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NOTES
ON
MILITARY EXPLOSIVES

BY
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FIRST THOUSAND



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PREFACE.

THESE notes were collected with a view to lecturing on the subject of Modern Military Explosives to the student officers at the Artillery School, Fort Monroe, Virginia. It was desired to give the officers a general knowledge of the modern explosives, including the composition and manufacture of the important military explosives; the general chemical and physical principles involved in explosive phenomena; the principles governing the storage, handling, and uses of explosives in demolitions and disruptive work.

No single work of recent publication appeared to cover this ground adequately. The admirable work of Guttman¹ is adapted rather to manufacturers, goes too minutely into details of manufacture, and includes some explosives not of special interest to military men. The lectures of Munroe² and Walke³ do not include the advances in explosives, especially in the nitro-powders, that have occurred since the later 90's. Berthelot's celebrated work is limited too strictly to the chemical and physical facts pertaining to explosive reactions.

After reviewing the field, it seemed that the only practical

¹ The Manufacture of Explosives. By Oscar Guttman. (Whittaker & Company.)

² Lectures on Chemistry and Explosives. By Professor Charles E. Munroe, Chemist to Torpedo Corps, U. S. Navy. (Torpedo Station Print.)

³ Lectures on Explosives. By Willoughby Walke, First Lieutenant, Fifth U. S. Artillery. (John Wiley & Sons.)

way to present the desired information was to collect from all available authorities and sources the facts desired, and arrange them in logical sequence.

This, accordingly, has been attempted. All the works named above and other publications, have been consulted and drawn upon, including Eissler's,¹ Wisser's,² Bernadou's,³ Bloxam's,⁴ Tillman's,⁵ and many current publications, including Reports of the Chief of Ordnance, U. S. Army; the Proceedings of the American and British Chemical Societies, Journal of the Society of Chemical Industry, Arms and Explosives, Proceedings of the Franklin Institute, Proceedings of the U. S. Naval Institute, Scientific American, Engineering, The Engineer, Journal of the Military Service Institution, Journal of the U. S. Artillery, and the Army service papers.

Owing to the fact that some of the officers of the classes had little or no knowledge of chemistry, it was found necessary to prepare a preliminary chapter on the principles of chemistry. The attempt has been made to do this in a statement of these principles in as simple terms and as briefly as possible. With a view to a better understanding of these principles, the theoretical statement of them has been reinforced by a few laboratory experiments, arranged with a view to illustrating the text proper. In a general way, these chemistry notes follow the method of treatment given in the first chapter of Tillman's General Descriptive Chemistry. A set of simple laboratory rules and notes is added for the benefit of those who have had no laboratory experience.

¹ A Handbook of Modern Explosives. By M. Eissler.

² Explosive Materials. By First Lieutenant John P. Wisser, First Artillery. (No. 70, Van Nostrand Science Series.)

³ Smokeless Powder, Nitrocellulose, and the Theory of the Cellulose Molecule. By John B. Bernadou, Lieutenant, U. S. Navy.

⁴ Chemistry, Inorganic and Organic, with Experiments. By the late Charles Loudon Bloxam, Professor of Chemistry in the Department of Artillery, Woolwich.

⁵ Descriptive General Chemistry. By Colonel S. E. Tillman, U. S. Army, Professor of Chemistry, U. S. Military Academy.

In connection with the preparation of these notes, most of the important powder-works and depots in the United States have been visited. I am under obligation for information and courtesies to the following individuals: the Messrs. Dupont, of Wilmington, Del.; Professor H. F. Brown, General Superintendent of the International Powder Works at Parlin, N. J.; the late Captain H. C. Aspinwall, General Superintendent of the Laffin & Rand Powder Works at Pompton, N. J.; the Chief of Ordnance, U. S. Army; the Chief of the Bureau of Ordnance, Navy Department; Major Orin B. Mitcham, Ordnance Department, U. S. A., Inspector of Powder, U. S. A.; Major Willoughby Walke, Artillery Corps, U. S. A.; Captain C. C. Williams, Ordnance Department, U. S. A.; Mr. Albert P. Sy, Chemist, late Chief Chemist U. S. Proving Grounds, Sandy Hook, N. J.

I am under special obligations to Major B. W. Dunn, Ordnance Department, U. S. A.; Captain John D. Barrette, Artillery Corps, U. S. A.; Captain Percy P. Bishop, Artillery Corps, U. S. A., and Captain Stanley D. Embick, Artillery Corps, U. S. A., for information, suggestions and assistance contributed.

The facts pertaining to magazines and demolitions are derived chiefly from the professional manuals of the Royal Engineers.

No attempt has been made to include those explosives which have no military application, or experimental explosives, the numbers of which are so great as to be beyond the limits of description in a treatise like this. Such explosives may be found enumerated and briefly described in Cundill's Dictionary of Explosives.

The rules of the American Railway Association governing the transportation of explosives are given in the Appendix.

E. M. WEAVER.

WASHINGTON, D. C.,
Sept. 12, 1906.

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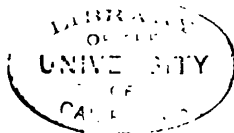
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NOTES ON MILITARY EXPLOSIVES.

I.

PRINCIPLES OF CHEMISTRY.

1. Before entering upon a study of explosives it is desirable that some knowledge be had of the fundamental chemical principles involved in the composition of explosive substances and in the changes which take place in connection with explosive phenomena. To this end a brief review will be given of the simple chemical laws, the system of notation, the meaning of chemical reactions, the relations of volumes and weights in these reactions, and problems arising thereunder.

Forms of Matter.

2. As a foundation, it is well to have some conception of the forms of matter as generally conceived at the present time. With this in view it is convenient to consider matter as occurring in the three following forms:

- (a) In the *mass*; including all aggregations from the smallest quantity perceptible to our senses to the great masses of the heavenly bodies.
- (b) In the *molecule*; which is defined to be that portion of a substance which has reached the limit of subdivision by physical means; that smallest portion of a given mass of a substance which, in a progressive process

of subdivision, would *retain all and only the properties of the substance*. If by any means a further subdivision be effected, some or all of the properties of the substance would be changed.

- (c) In the *atom*; which is the smallest portion of any given kind of simple matter that has been differentiated in scientific investigations by reasoning processes.¹

3. The *atom* is the ultimate unit of matter so far as known; ¹ the *molecule* is an aggregation of atoms; the *mass*, or *body*, is an aggregation of molecules.

4. A body may be *homogeneous*, like a piece of copper or salt, or *heterogeneous*, like a piece of granite. Homogeneous bodies contain only *one kind* of matter; heterogeneous, more than one kind; granite, for example, is made up of three kinds of matter called, respectively, feldspar, quartz, and mica.

5. Homogeneous matter implies only similarity of the molecules; it is made up of similar molecules. With similar molecules there would of course, from the definition of a molecule, be similar physical properties throughout the mass.

6. It is known that molecules are of two kinds also: those made up of *atoms of the same kind* and those made up of *atoms of different kinds*. The former are called *elementary molecules*; the latter, *compound molecules*.

¹ As a result of investigations consequent on the discovery of radium and the properties of other radio-active substances, a new theory of the constitution of matter has recently been enunciated by Prof. J. J. Thomson, F.R.S. According to this theory, the atom of any elementary substance is made up of particles charged with negative electricity, suspended throughout a larger mass charged with positive electricity. The number of negative particles and the resulting attractions and repulsions between the charged negative and positive masses determine the constitution of the atom. The negative particles are called *corpuscles*, and the theory, from these, is called *the corpuscular theory of matter*. Since the atom is ordinarily neutral, the quantity of negative charge must equal the quantity of positive charge. The mass of a corpuscle is constant, and is computed to be about $\frac{1}{1836}$ of the mass of the hydrogen atom. Assuming the corpuscle to be a sphere, its radius is computed to be about 10^{-13} cm., and its ratio to the radius of the hydrogen atom about 10^{-5} . The masses positively charged appear to vary; the smallest, however, is at least equal to the hydrogen atom.

7. Homogeneous bodies made up of the same elementary molecules are called *elements*; if made up of compound molecules, they are called *compounds*.

8. Any body will be either (1) homogeneous and an *element* or a *compound*, or (2) *heterogeneous*, made up of different elements or compounds, or a mixture of these two classes; this form of matter is also called a *mixture*.

9. More than seventy elements have been isolated; that is, so far as known at present there are at least this number of different *atoms*. Future investigations may discover new elements, or disclose that some now thought to be elements are compounds.

Properties of Atoms.

10. The atom of each element has its own proper weight, which is different from the weight of any other atom. The lightest known atom is that of the element Hydrogen; the weights of all other atoms are expressed in terms of the weight of the hydrogen atom as a unit.

11. The elements are grouped into two classes, namely:

- (1) The *metals*; those possessing properties like copper, iron, gold, etc.
- (2) The *non-metals*; those possessing properties like carbon (charcoal, graphite, diamond), sulphur, phosphorus, etc.

12. The following are the names of the most important elements, and opposite each name is placed the weight of its atom in terms of the hydrogen atom as unity.

METALS.

Name.	At. Wt.	Symbol.	Valency.
1. Potassium.	38.8	K' (Kalium)	I.
2. Sodium.	22.9	Na' (Natrium)	I.
3. Barium.	136.4	Ba''	II.
4. Strontium.	86.9	Sr''	II.
5. Calcium.	39.8	Ca''	II.
6. Magnesium.	24.1	Mg''	II.
7. Aluminum.	26.9	Al'''	III.
8. Zinc.	64.9	Zn''	II.

METALS—Continued.

Name.	At. Wt.	Symbol.	Valency.
9. Nickel.....	58.2	Ni ^{''''}	II or III.
10. Cobalt.....	58.5	Co ^{''''}	II or III.
11. Iron.....	55.5	Fe ^{''''} (Ferrum)	II or III.
12. Manganese.....	54.6	Mn ^{''/iv}	II or IV.
13. Chromium.....	51.7	Cr ^{''/vi}	III or VI.
14. Copper.....	63.1	Cu ^{''} (Cuprum)	I or II.
15. Lead.....	205.3	Pb ^{''} (Plumbum)	II.
16. Tin.....	118.1	Sn ^{''/iv} (Stannum)	II or IV.
17. Tungsten.....	182.6	W ^{vi} (Wolframium)	VI.
18. Antimony.....	119.5	Sb ^{'''/v} (Stibium)	III or V.
19. Mercury.....	198.5	Hg ^{''} (Hydrargyrum)	I or II.
20. Silver.....	107.1	Ag ['] (Argentum)	I.
21. Gold.....	195.7	Au ^{'''} (Aurum)	III.
22. Platinum.....	193.4	Pt ^{''/iv}	II or IV.

NON-METALS.

1. Oxygen.....	15.8	O ^{''¹}	II.
2. Hydrogen.....	1.0	H [']	I.
3. Nitrogen.....	13.9	N ^{'''/v}	III or V.
4. Carbon.....	11.9	C ^{iv}	IV.
5. Silicon.....	28.2	Si ^{iv}	IV.
6. Sulphur.....	31.8	S ^{''}	II.
7. Phosphorus.....	30.7	P ^{'''/v}	III or V.
8. Chlorine.....	35.1	Cl [']	I.
9. Iodine.....	125.9	I [']	I.
10. Bromine.....	79.3	Br [']	I.
11. Fluorine.....	18.9	F [']	I.

13. These twenty-two metals and eleven non-metals, either separately or in combination, make up more than ninety per cent of all known matter. The weights of these atoms are the constants in all chemical computations in which they enter. Where the weight is greater or less than 5 after the decimal point, it will be sufficient to take the nearest unit in ordinary chemical computations.

¹ As to the standard for atomic weights, some chemists prefer to take the weight of the oxygen atom as the standard, calling it 16, instead of that of the hydrogen atom, unity. The reason for this is that oxygen forms a greater number of compounds, and they are susceptible of more exact analysis than many of the hydrogen compounds. An uncertainty exists as to the ratio between the atomic weights of H and O. Late determinations make O=15.8 when H=1, or H=1.008 when O=16.

14. Besides weight, atoms possess another important property. They have *mutual attractions for the same kind and for certain different kinds* of atoms. The *intensity* of these attractions vary for different atoms, but, like the weights, are always constant for the same atom. This attraction existing among atoms is called *affinity*, or *chemical affinity*. Just as *gravity* or *weight* is a property of matter in mass, by means of which bodies fall to the earth, so affinity is a property of atoms, by means of which they come together and combine, when released from one set of conditions in a molecule, to form a new set in a new molecule. Atoms do not as a rule exist separately in nature; if free, they will associate themselves either with atoms of the same kind or with atoms of a different kind, forming thereby the *elementary* and *compound* molecules described above.

15. Atoms have still another important property. In the molecules formed by the action of the so-called force of affinity, as described in the last paragraph, it is found that one atom requires one, two, three, and so on, atoms of other elements to combine with it to form molecules. This property of atoms which determines *the relative number of atoms*, in any case, that enter into chemical combination in forming molecules is called *valency*.

16. Elements are classified according to the valency of their respective atoms. The valency of the hydrogen atom is taken as the *unit of valency*.

17. There are certain atoms that do not combine with the hydrogen atom. The valency of the atoms of elements whose atoms do not combine directly with the hydrogen atom is determined through their combination with the atom of some element that does combine with the hydrogen atom. Thus: the lead atom and the zinc atom do not combine with the hydrogen atom, but all three of these atoms combine separately with the oxygen atom, and from this fact the relative valencies of the lead and zinc atoms may be obtained with respect to hydrogen.

18. An element whose atom has the same combining power (valency) as the hydrogen atom, that is, combines atom for atom with the hydrogen atom or its equivalent, is said to be

univalent, or is called a *monad*. An element whose atom has twice the combining power of the hydrogen atom, that is, will combine with two atoms of hydrogen, or two atoms of any *univalent* element, is said to be *bivalent*, or is called a *dyad*. An element whose atom has three times the valency of the hydrogen atom is said to be *trivalent*, or is called a *triad*, and so on. The degree of valency is represented by small ticks or Roman numerals placed to the right and above the atomic symbol, thus: H' , O'' , N''' , C^v (see table, pages 3 and 4, for valencies).

Notation.

19. For convenience, atoms are represented in chemistry by *symbols*. These symbols are the initial letters of the ordinary or Latin names of the elements, or the initial and one other letter selected therefrom. These symbols are also often used as abbreviations of the name of the element. These two uses should be kept distinctly in the mind. In all chemical equations and computations the symbols represent definitely the weights of atoms. The symbols of the more important elements will be found in the table on pages 3 and 4.

20. A single atom is represented by the simple symbol. Thus: one atom of hydrogen, H ; one atom of calcium, Ca ; one atom of lead, Pb .

21. Two or more atoms may be represented either by placing the number as a coefficient in front of the symbol, or writing it as a subscript to the right and below. Thus: two atoms of oxygen, $2O$ or O_2 ; three atoms of iron, $3Fe$ or Fe_3 .

22. An elementary molecule composed of two atoms would be indicated as explained in the last paragraph. Thus, the molecule of nitrogen contains two atoms; it is represented by N_2 . The molecule of phosphorus contains four atoms; its molecule would be expressed by P_4 .

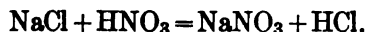
23. A compound molecule is represented by writing the symbol of each element which enters it side by side, and giving to each symbol a numeral subscript to indicate the number of atoms of each element. Thus: the molecule of sulphuric acid

is known to contain two atoms of hydrogen, one atom of sulphur, and four atoms of oxygen; it would be represented in symbolic notation by H_2SO_4 . In the same way, the molecule of alcohol is known to contain two atoms of carbon, six atoms of hydrogen, and one atom of oxygen; its molecular symbol would be $\text{C}_2\text{H}_6\text{O}$. The group of symbols used to represent a compound molecule is called the *formula* of the compound, or the *molecular formula* of the compound.

24. In case two or more molecules of the same compound are considered, the proper coefficient is placed before the symbol, or a parenthesis may be placed about the symbol and the number of molecules indicated by a numeral subscript. Thus: two molecules of sulphuric acid, $2\text{H}_2\text{SO}_4$ or $(\text{H}_2\text{SO}_4)_2$; three molecules of alcohol, $3\text{C}_2\text{H}_6\text{O}$ or $(\text{C}_2\text{H}_6\text{O})_3$.

Reactions.

25. These symbols are made use of in chemical writings in indicating the changes which take place when chemically interactive substances are brought together under conditions which excite or permit interaction among their constituents. This is done by representing the substances which are brought together by their proper symbols, writing the sign plus (+) between the symbols of the separate substances used, writing the equality sign (=) after the last substance used, then writing, in the same way, the symbols of the substances resulting from the chemical combinations which have taken place. That is, the *form of an equation is made use of to abbreviate the description that would otherwise be necessary*. For example, the fact that 58 parts by weight of common salt (symbol NaCl) mixed with 63 parts of nitric acid (symbol HNO_3) produces 85 parts of sodium nitrate (symbol NaNO_3) and 36 parts of hydrochloric acid (symbol HCl) would be represented thus:

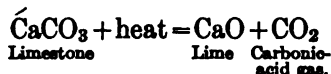


Such an equation is only a means to abbreviate the description of chemical changes by using symbols. It is called a *reac-*

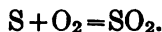
tion. The substances on the left of the equality sign are called *reagents*; those on the right, *products*.

26. It should be kept clearly in mind that such equations are quite different from algebraic equations. No mathematical operations can be performed with them. They simply express the fact that the substances on the left of the equality sign will produce those on the right. The total numbers of each kind of atom and the total weights must, of course, be the same on each side; in this sense, only, are *reactions* equations.

27. There are three kinds of reactions, namely, *analytical*, *synthetical*, *metathetical*. An *analytical reaction* involves a disintegration of a compound, separating the constituent elements, or reducing it to simpler chemical forms. For example, limestone is a compound of carbon, oxygen, and calcium, and if a piece of limestone be heated, some of the carbon and oxygen will pass off, in combination, as a gas, leaving the calcium and the rest of the oxygen in combination. This reaction may be represented as follows:



A *synthetical reaction* involves a combination of elements or compounds and the formation of substances of a more complex nature than the original ones. Thus, if sulphur be heated to a high temperature in an atmosphere of oxygen, the oxygen and sulphur will combine, forming a sulphur-oxygen compound. The reaction would be represented as follows:

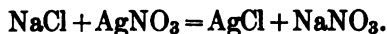


If this compound be mixed with water, a new compound is formed, the reaction being represented as follows:

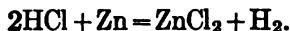


A *metathetical reaction* involves the interchange of atoms between two substances, or the displacement of one element

in a compound by a single separate element or a group of elements. Thus, if a solution of common salt (sodium chloride) be treated with a solution of silver nitrate, the sodium of the salt and the silver of the nitrate will exchange places, giving silver chloride and sodium nitrate, the reaction being represented as follows:



Again, if metallic zinc be immersed in hydrochloric acid, the zinc will displace the hydrogen of the acid, the reaction being represented as follows:



Nomenclature.

28. There are certain rules followed in the naming of the elements and compounds which may be briefly stated as follows:

29. The more recently discovered *metals* have names ending in *um*, and some of the more recently discovered *non-metals* have names ending in *ine*. Examples: metals—sodium, ferrum; non-metals—chlorine, iodine.

30. *Compounds composed of two elements* are called *binary compounds*. Such compounds are written with the symbol of the non-metal or the more non-metallic element last, and the name of the compound is given by the name of the first element followed by the name of the second element with the ending *ide*. Thus: common salt is a compound of the metal sodium and the non-metal chlorine; its symbol would be written thus, NaCl, and its name is given by the name of the metal followed by the name of the non-metal, replacing the ending *ine* by *ide*, making the full name of the binary *sodium chloride*. In the same way, FeO is iron oxide; NO, nitrogen oxide; CO, carbon oxide.

31. The combination of oxygen with another element follows this nomenclature rule, forming a large class of binary compounds called "oxides." Oxygen combines with a great

many elements, some metallic and others non-metallic;¹ the resulting binary compounds constitute two distinct classes of oxides. These two classes have distinct properties, and are called, respectively, the *metallic or basic oxides* and the *non-metallic or acid oxides*.

32. The terms *base* and *basic*, *acid* and *acidic* have important meanings in chemistry. They are suggestive of the manner in which the force of affinity will act in any particular case. Bases and acids are the opposites in chemical action. A substance that possesses basic properties suggests chemical union with a substance possessing acidic properties. The tendency of bases and acids to combine depends on their strengths as bases and acids; the strongest or most pronounced bases have the greatest tendency to unite chemically with the strongest acids. As the two classes—bases and acids—approach each other in the scale of chemical affinity, the tendency to unite is less marked. Difference of chemical affinity is, as it were, a difference of chemical potential. As difference of electrical potential suggests *capacity* for electrical work, so the relative basic or acidic properties of substances suggest capacity for chemical combination.

33. Speaking generally, the result of the combination of basic and acidic substances is a third class of substances called *salts*. Many salts possess neither basic nor acidic properties: they are the chemical neutrals; such represent zero difference of chemical potential under the particular conditions.

34. There are simple tests to determine whether certain particular substances are basic, acidic, or neutral. A substance that is chemically active as an acid will turn blue litmus red; one that is chemically active as a base will turn reddened litmus blue. A salt that is perfectly neutral will have no effect on either red or blue litmus. There are other color tests for acids and bases, and, of course, the whole range of chemical reactions to determine the basic, acidic, or neutral properties of sub-

¹ See Experiments Nos. 1 and 3.

stances and the degree thereof, but the litmus test is sufficient for the limits of these notes.

35. The principles given in paragraphs 32 and 33 give rise to a general classification of substances into *bases*, *acids*, and *salts*.

36. There are other rules governing the naming of compounds which may be introduced here.

37. Both *prefixes* and *suffixes* are resorted to to specify particular compounds. For example, nitrogen combines with oxygen in several proportions, forming separate oxides; these may be written as follows:

1. N_2O Nitrogen *monoxide*.
2. N_2O_2 Nitrogen *dioxide*.
3. N_2O_3 Nitrogen *trioxide*.
4. N_2O_4 Nitrogen *tetraoxide*.
5. N_2O_5 Nitrogen *pentoxide*.

They are designated by using the prefixes *mon-*, *di-*, *tri-*, *tetra-*, and *pent-* before the word oxide, as indicated above.

38. Binary compounds in which there are three atoms of the second element to two atoms of the first element may be designated by the prefix *sesqui-* placed before the second with its proper ending. Thus, N_2O_3 is nitrogen sesquioxide; Fe_2O_3 is iron sesquioxide; Sb_2S_3 is antimony sesquisulphide.

39. The suffixes *-ous* and *-ic* are used after the first element of a binary compound to indicate which of *two* compounds is meant, in cases where but two compounds are formed between the two elements considered, or in cases where there are several and two are more important. Thus: sulphur forms two principal oxides, namely, SO_2 and SO_3 ; the first, or *lower*, degree of oxidation takes the suffix *-ous*, being called sulphurous oxide (or sulphur dioxide); the second, or *higher*, oxide takes the suffix *-ic* and is called sulphuric oxide (or sulphur trioxide). Also, iron forms three oxides, FeO , Fe_2O_3 , and Fe_3O_4 ; the first is called ferrous oxide, and the second ferric oxide.

40. The prefix *hypo-* is sometimes used before a compound to indicate a still lower degree of oxidation than the *-ous*. Thus, there is a *hyposulphurous* acid which contains less oxygen than sulphurous acid.

41. The prefix *hyper-* is similarly used before compounds to indicate a higher oxidation; and the prefix *per-* to indicate the highest degree of oxidation. Thus Fe_3O_4 above is the *peroxide* of iron, or iron *peroxide*.

42. While these uses of prefixes and suffixes are explained for oxides only, they may be used also in the case of other compounds; in all cases they indicate the degree of combination of the non-metallic element. Thus, mercury has two chlorides, HgCl and HgCl_2 . The former is mercury *monochloride*, or *mercurous chloride*; the latter is mercury *dichloride*, or *mercuric chloride*, or mercury *perchloride*.

43. Instead of using the metal or more metallic element as an *adjective* and the non-metal or more non-metallic element as a noun, it is just as correct to use the *prepositional phrase equivalent*. For example, instead of nitrogen dioxide, the *dioxide of nitrogen*; instead of mercury perchloride, the *perchloride of mercury*, etc.

44. The prefix *proto-* is sometimes used to indicate an atom for atom combination; thus, HgCl above is sometimes called the *protochloride* of mercury, PbO , the *protoxide* of lead, etc.

45. Many of the *acid* oxides, like SO_2 , SO_3 , CO_2 , N_2O_5 , etc., unite with water, H_2O , forming a class of compounds known as *oxyacids*.¹ These possess in a marked degree acid properties, combining readily with bases to form salts.

46. Oxides which thus unite with water to form oxyacids are sometimes called *acid anhydrides*, or simply *anhydrides*.

47. The *oxyacids* are designated by the same suffixes as the acid oxides which form them; thus, sulphurous oxide (SO_2) forms sulphurous acid, and sulphuric oxide (SO_3) forms sulphuric acid, etc. This may be represented by reactions thus:

¹ See Experiment No. 5.



48. The salts formed from acids having the *-ous* suffix are designated by the suffix *-ite*.¹ Thus, salts formed from sulphurous acid are called *sulphites*; from nitrous acid, *nitrites*, etc.

49. The salts formed from acids having the *-ic* suffix are designated by the suffix *-ate*.² Thus, salts formed from sulphuric acid are called *sulphates*; from nitric acid, *nitrates*; from carbonic acid, *carbonates*, etc.

50. There is another class of acids which do not contain oxygen. These are called *hydracids*.³ They contain only hydrogen and some non-metal. Such acids are HCl, called hydrochloric acid, and HS₂, called sulphydric acid.

51. The salts formed from hydracids take names according to the *binary rule*; ⁴ salts from HCl are called *chlorides*; from sulphydric acid, *sulphides*.

52. Both oxyacids and hydracids contain hydrogen, and the fundamental characteristic and most important chemical property of these acids is that they *will often exchange all or a portion of the hydrogen they contain for a metal*, whether the metal be alone or in combination with other elements,⁴ forming thereby salts.

53. The term *basicity* is used with respect to acids to indicate the number of hydrogen atoms which are replaceable by a metal or equivalent in chemical union. Thus, H₂SO₄ is a *bibasic* acid, HCl is *monobasic*, etc., since in the former two atoms of hydrogen are replaceable by a metal or equivalent, and in the latter there is but one atom to be so replaced.

54. Some of the common acids are indicated by the following names and formulas of their molecules:

¹ See Experiment No. 10.

² See Experiment No. 6.

³ See Experiment No. 11.

⁴ See Experiment No. 7.

MONOBASIC ACIDS.

Hydrochloric. . . . HCl
 Nitrous. HNO₂
 Nitric. HNO₃

BIBASIC ACIDS.

Sulphydric. . . H₂S
 Sulphurous. . . H₂SO₃
 Sulphuric. . . . H₂SO₄
 Carbonic. H₂CO₃
 Hydric. H₂O (see par. 58).

55. Acids may be graded, according to their respective *avidities*, with respect to nitric acid as a standard. The term *avidity* being used to indicate the proportion of a base that any given acid will combine with, when equivalent quantities of the given acid and nitric acid are mixed separately, with a solution of the given base. Any base may be used. The avidities of the three standard acids at ordinary temperatures have been established as follows: HNO₃=1; H₂SO₄=0.5; HCl=1. That is, in solutions of equal concentration HCl and HNO₃ are stronger acids than H₂SO₄. But if heat be applied, the greater volatility of the first two will enable H₂SO₄ to displace them from salts.

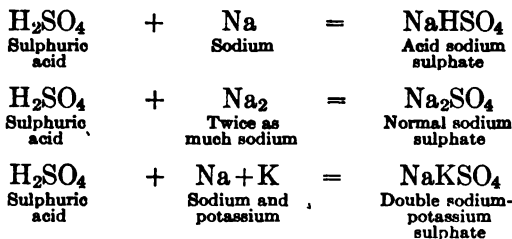
56. A bibasic acid may form three kinds of salts, depending on whether all of the hydrogen or a portion only is replaced, and whether one or two metals are used. These salts are named as follows:

Acid salt, when only half the hydrogen is replaced.¹

Normal salt, when all of the hydrogen is replaced and by one² metal.

Double salt, when all of the hydrogen is replaced and by two metals.

EXAMPLES.

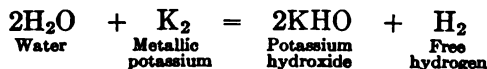


¹ See (a), Experiment No. 10.

² See (b), same experiment.

57. Compounds containing three different elements are called *ternary* compounds; e.g., H_2SO_4 ; those containing four different elements are called *quaternary* compounds; e.g., NaKSO_4 ; etc.

58. The principal basic substances are the metallic oxides¹ and another group of substances called *hydroxides*. Oxygen combines with hydrogen in two proportions: first, one atom of oxygen to two atoms of hydrogen, forming *water*; and, secondly, one atom of oxygen to one atom of hydrogen, forming *hydroxyl*. Water exists in nature as a stable liquid; hydroxyl exists only in an imaginary way in combination with some metal or other chemical equivalent. In the table of acids on page 14 it is to be noted that water is classed as an acid. It comes under this classification only in that it has the property of exchanging its hydrogen for certain metals. (It is neutral to blue litmus and has no other characteristic acid property.) The most important in a chemical sense of these metals are *potassium*, *sodium*, *lithium*, *cæsium*, *rubidium*; especially the first two. These or their oxides act on water directly to decompose it displacing one of the two hydrogen atoms,² thus:



The oxides of these metals form hydroxides, as follows:



without giving off free hydrogen.

59. Metallic oxides which combine with water to form hydroxides are sometimes called basic anhydrides.

60. The rule for writing and naming oxides applies to

¹ The oxides of the metals as a rule neutralize acids, forming salts, and behave in this way as bases. There are some few metallic oxides like SnO , and Sb_2O_3 , which are "anhydrides," forming acids with water. No non-metallic oxide is known to have basic properties. There is another class of oxides, both metallic and non-metallic, which are neutral, such as water (H_2O), and the black oxide of manganese, MnO_2 . But the general rule is that *metallic oxides are basic and non-metallic oxides are acid*.

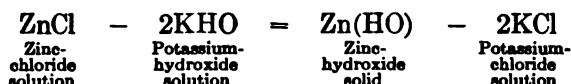
² See (a), Experiment No. 2.

hydroxides. HO is written after the metal and the ending *ide-* is used; thus, KHO is *potassium hydroxide*, or *hydroxide of potassium*.

61. The hydroxides of the metals named in paragraph 58 constitute a group of the strongest bases and are called *alkalies*. One other hydroxide is included in the alkalies, namely, ammonium hydroxide, $\text{NH}_4(\text{HO})$.

62. A second group of hydroxides, formed by the *direct* action of metals or their oxides on water,¹ are those known as the *alkaline earths*. These are the hydroxides of calcium, $\text{Ca}(\text{HO}_2)$; barium, $\text{Ba}(\text{HO})_2$; strontium, $\text{Sr}(\text{HO})_2$; and magnesium, $\text{Mg}(\text{HO})_2$. These rank next to the alkalies in strength as bases.

63. The hydroxides of other metals cannot be formed directly by the action of the metals or their oxides on water.² They are formed by combining one of the alkalies or alkaline earths in solution with a solution of some soluble salt of the metal. Thus, zinc hydroxide may be formed by mixing a solution of zinc chloride with a solution of potassium hydroxide, the reaction being represented thus:



64. In general and for the purposes of these notes, it may therefore be said that substances may be classified chemically as follows:

- | | | |
|---------------|---|--|
| <i>Acids.</i> | { | Oxides of the non-metals (acid oxides). |
| | | Oxyacids (union of acid oxides with water). |
| | | Hydracids (union of hydrogen with certain non-metals, but not oxygen). |
| <i>Bases.</i> | { | Oxides of the metals (basic oxides). |
| | | Hydroxides (union of basic oxide or metal with water). |
| <i>Salts.</i> | | Neutral substances resulting from the combination of acids and bases. |

¹ See (b), Experiment No. 2.

² See (c), Experiment No. 2.

Radicals.

65. It has been stated that oxygen may be considered as existing in combination with hydrogen in chemical substances in the proportion of one atom of oxygen to one atom of hydrogen, HO, and that the name hydroxyl has been given to this particular combination. It should be understood here that there is no substance in nature existing separately, having the molecular formula HO. The oxides of hydrogen which do so exist are H_2O_2 and H_2O . The combination HO is therefore purely imaginary. The assumption of its existence is made because, in the chemical changes which take place in the formation and decomposition of the class of hydroxides the proportions of hydrogen and oxygen represented by HO are found invariably associated together. *Groups of atoms which are found to thus persist together throughout chemical reactions are called compound radicals, or often simply radicals.* (The atoms of the elements are the "*elementary radicals.*") Often such groups are written either inclosed in parentheses or pointed off by periods thus: K.HO or K(HO) ; Zn(HO)_2 ; Ca(HO)_2 . There are many possible groupings of atoms, but only those which are found to exist in chemical analysis and synthesis are legitimate radicals.

66. Compound radicals are considered to have valencies the same as atoms of elements. Hydroxyl, for example, is univalent and will combine with only one univalent atom or another univalent compound radical. Other important compound radicals are:

Amidogen.....	NH_2' , valency 1.
Methyl.....	CH_3' , valency 1.
Carbonyl.....	CO'' , valency 2.
Nitroxyl or nitryl.....	NO_2' , valency 1.
Cyanogen.....	CN' , valency 1.

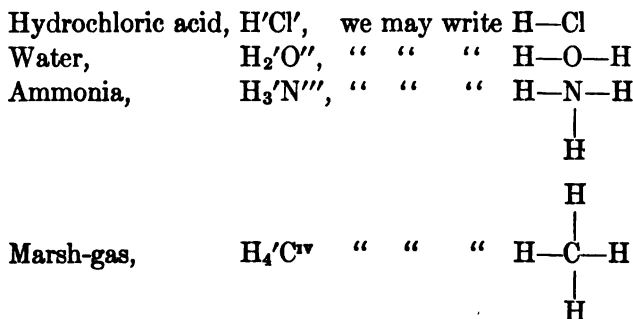
67. Compound radicals have basic or acid properties or are neutral, the same as elementary radicals. Radicals composed of the two elements carbon and hydrogen only, are

usually basic; if oxygen is also present, the radical is usually acid.

68. Basic radicals, whether compound or elementary, are electropositive; acid, electronegative.¹

Graphic Formulas.

69. The valency of atoms and compound molecules, and the manner in which the units of valency in any molecule are satisfied or grouped, are often represented graphically by joining together the symbols with small lines, each line representing a unit of valency. Thus, for



The manner in which valency is satisfied by such graphic formulas may be understood better, perhaps, by imagining each atom, as represented by its symbol, to have bonds or hooks extending from it, and each bond or hook having capacity for engaging with a free bond or hook of another atom. Suppose, for example, that the H's, in the above formulas, are connected with the other bonds or hooks as indicated by the lines between the letters.

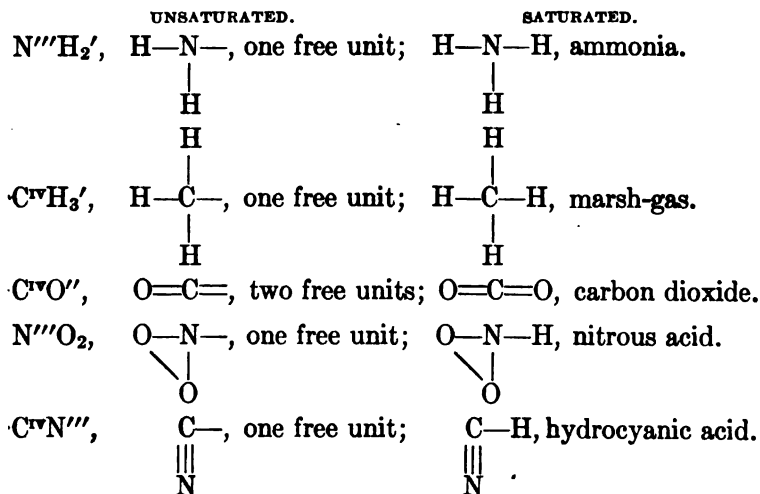
The hooks linking, or the bonds attaching them together, in a measure represent the idea involved in "satisfying" units of valency. Such formulas are called *graphic* or *structural formulas*. They merely indicate how valency may be supposed to be satisfied in combinations. They do not represent the relative positions of atoms in molecules.

¹ This fact has a bearing on the corpuscular theory of matter (see note bottom of page 2).

70. When all the units of valency are satisfied, as in the groups in paragraph 69, the molecule is said to be *saturated*.

71. Elements whose atoms have an even number of units of valency are called *artiads*; those whose atoms have an odd number of units of valency are called *perissads*. In any *saturated* molecule the *sum of the perissad atoms* is always even. This is the *law of even numbers*.

72. An unsaturated molecule is one having one or more units of valency unsatisfied. The compound radicals in paragraph 66 are unsaturated. The free units of valency and the consequent combining power of these radicals respectively may be determined by writing out their graphic formulas, thus:



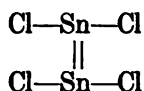
73. If valency be a definite property of atoms, it is necessary to account for what appear to be variations in valency, or *variable valency*. Thus, it is known that chlorine has but one unit of valency, yet tin and mercury unite in two proportions with chlorine, as follows:

1. SnCl_2
2. SnCl_4
3. HgCl
4. HgCl_2

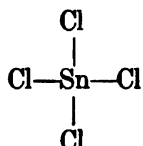
In 1, Sn has a valency of II; in 2, of IV; in 3, Hg has a valency of I; in 2, of II.

The question arises, How can such variations as these be reconciled with a constant atomic property? The use of graphic formulas may assist in explaining such seeming contradictions.

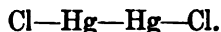
If the graphic formulas of the compounds referred to be written as follows, all units of valency are satisfied, and in each case there is the proper proportion by weight and constant valency for each atom. For SnCl_2 we may write Sn_2Cl_4 or $(\text{SnCl}_2)_2$, preserving the proportions by weight; that is, consider *two molecules* instead of *one molecule* to be involved in the condition of saturation. The graphic formula for *this* condition would be, assuming Sn to have a valency of IV, the highest:



and for SnCl_4 the graphic formula would be



For HgCl we may write Hg_2Cl_2 or $(\text{HgCl})_2$, and the graphic formula of this is, assuming Hg to have valency of II, the highest:

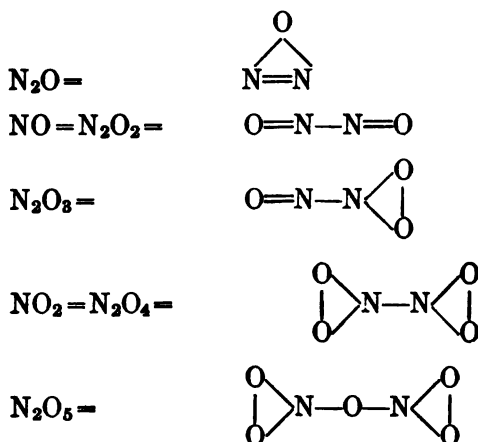


Again, for HgCl_2 , valency still II:



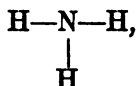
Other cases of seeming variable valency may be similarly explained by considering the proper grouping of molecules.

The series of the nitrogen oxides may be represented by the following graphic formulas, taking valency of nitrogen III:



74. If variable valencies may be thus explained, the original definition of valency may be adhered to, namely, it is the greatest number of univalent atoms an atom will combine with.¹

75. The equivalent weight of any element is that weight of it which combines with, is substituted for, or otherwise is chemically equivalent to, one atomic weight of hydrogen, in a completely saturated molecule. Thus: Ammonia, NH_3 ,



is a completely saturated molecule. The equivalent weight of nitrogen is $\frac{1}{3}$ of the atomic weight of nitrogen, since it combines with 3 atoms of hydrogen; that is, its equivalent weight is $\frac{14}{3} = 4.67$. H_2O is a completely saturated molecule; therefore the equivalent weight of oxygen is one-half its atomic weight, that is, 8.

76. Accepting these definitions, the valency of any element is equal to its atomic weight divided by its equivalent weight.

Organic and Inorganic Chemistry.

77. Substances which result from the operation of life

¹The model atoms displayed by Professor J. J. Thomson in his lectures on the corpuscular theory of matter appear to support this conclusion.

functions, either animal or vegetable, are called organic substances, and that portion of chemistry which treats of them is called organic chemistry. Substances obtained as minerals from the earth and which are not directly the result of life are called inorganic substances, and that portion of chemistry which treats of them is called inorganic chemistry.

Objects of Chemistry.

78. The objects of chemistry may be enumerated as follows:

(1) To study the properties of a substance so as to be able to identify it with certainty under whatever conditions it may be met with.

(2) To ascertain a method of producing it at pleasure.

(3) To determine its precise composition by weight and volume.

(4) To investigate its action with other substances and the phenomena associated therewith.

Physical and Chemical Phenomena.

79. In studying the properties of substances it is important to distinguish between physical properties, changes, and effects and chemical properties, changes, and effects. All mass effects, outside the limits of molecules and between molecules, which do not affect the integrity of any of the molecules of the mass, pertain to physical phenomena. All effects within the limits of molecules and between the atoms of different molecules, which accomplish disintegration of molecules and the rearrangement of atoms as constituents of new molecules, pertain to chemical phenomena.

Thus the physical properties of a substance include the state of aggregation of its molecules, as gas, liquid, or solid; its color, odor, taste, hardness, specific gravity, form of crystal, fusing-point, and boiling-point.

The chemical properties of a substance include its classification as an acid, a base, or a salt; the action of acids, bases, or salts with it; its composition; its production.

Mixtures, Solutions, Alloys, Amalgams.

80. In addition to the elementary substances and the homogeneous compounds there are other aggregations of matter which may be classified as mechanical mixtures, alloys, and amalgams.

81. A mechanical mixture consists of two or more unlike solids mixed together in any proportions of the constituents. It differs essentially from a chemical compound in that the proportions of the constituents of the latter are always the same by weight. Each constituent of a mechanical mixture always retains its own distinguishing physical properties, whereas in a true compound the characteristic physical properties of the separate constituents disappear. Granite is a mechanical mixture of quartz, feldspar, and mica; these ingredients may vary throughout all possible proportions, and although the physical properties of the separate constituents remain the same, those of the conglomerated mass vary to correspond to the varying proportions of the constituents; it is nevertheless always granite. Marble, on the contrary, is a chemical compound, and the proportion by weight of calcium, carbon, and oxygen is always the same; the physical properties of the mass are always the same, but the physical properties of the constituents have completely disappeared. Among explosives, black and brown powders are mechanical mixtures of potassium nitrate, carbon, and sulphur; guncotton is a chemical compound, composed of carbon, hydrogen, and oxygen.

82. A solid, liquid, or gas may be in solution in a given liquid; the latter is called the solvent. In passing into solution the solid liquefies and mixes with the solvent; the liquid mixes directly, and, when a homogeneous solution obtains, the two liquids are said to be mixable or miscible; gases are absorbed, so to speak, into the body of the solvent, the amount of gas passing into solution being directly proportional to its pressure on the surface of the solvent and inversely proportional to the temperature of the solvent. As a rule the quantity of a solid that will dissolve increases with the temperature of the solvent.

Simple solution appears often to be a *quasi* chemical as well as physical phenomenon, though there is usually a reduction of temperature due to the physical change of the solid to liquid state. In chemical solution there is chemical combination.

83. A solvent will take up only a limited quantity of a soluble substance; when this quantity has been taken up further addition only causes an accumulation in the liquid of the solid in the solid state. At this stage the solvent is said to be saturated and the solution is called a saturated solution. Fractional solutions may be made in percentage quantities required from a saturated solution. A saturated solution is sometimes called a normal solution; often a normal solution is defined as such that each litre contains the number of grains of the substance equal to its equivalent weight. A standard solution is such that each litre contains a known and definite amount of the substance. There may be an infinite number of standard solutions of a substance.

84. Proximity of molecules favors chemical action. The form of solution is particularly favorable, both for the reason that the molecules are closer together than in the gaseous state, and the action of affinity is not interfered with by the force of cohesion which acts between the molecules of substances in the solid form.

85. Alloys partake of the nature of solidified solutions of two or more metals mixed together in the molten state. The constituents may vary in any proportion.

86. An amalgam is a union of a metal with mercury. Iron is the only metal in common use which does not form amalgams readily with mercury. Amalgams approach more nearly to compounds than alloys or solutions.

87. The single molecule is invisible. In order that matter become visible the molecules must be brought to within certain limits of nearness to each other. In the state of gas the molecules are not sufficiently close to each other to produce visibility. The passage from visibility to invisibility is well illustrated in the disappearance of condensed steam escaping

from an engine. The proximity of molecules in the liquid and solid states causes visibility.

88. The passage from a liquid or solid state to gaseous is called evaporation, or vaporization. Water evaporates whether in the liquid or solid form (ice or snow). Camphor and a few other solids vaporize directly, like ice; notably $(\text{NH}_4)\text{Cl}$ and S.

89. The passage from the solid state to liquid by the application of heat is fusion, and the temperature at which the change of state takes place is the fusing-point. If the temperature be raised from the fusing-point until vaporization begins in the interior of the liquid as well as on the surface, the latter temperature is the boiling-point. All fusible substances have definite, characteristic fusing- and boiling-points

90. The change of state from vapor to liquid or vapor to solid is condensation. The cycle of change from solid or liquid to vapor back to liquid is distillation; from solid to vapor back to solid, sublimation.

91. When a solid absorbs moisture directly from the air at ordinary temperatures and combines therewith to form a liquid, the phenomenon is called deliquescence.

92. Change of state from solid to liquid, solid to vapor, or liquid to vapor causes a disappearance of heat; that is, there is a lowering of temperature. The reverse series of changes cause a corresponding and equal development of heat—elevation of temperature.

93. As a rule chemical actions resulting in the building up of compound molecules from elementary molecules, or which increase the complexity of the molecules (synthetical reactions), involve evolution of heat. Reactions resulting in a separation of the constituents into elements or simpler molecules involve, as a rule, disappearance of heat. In any particular case precisely the number of heat-units made evident in synthesis are made latent or disappear in analysis.

94. There are certain exceptions to the rule given in the last paragraph. There are some molecules, like nitrous oxide,

N_2O , and potassium chlorate, $KClO_3$, and fulminate of mercury, $HgO_2C_2N_2$, which absorb heat in formation and give off heat in disintegration. This property has an important bearing in explosives. Such molecules are said to be endothermic. Molecules which give off heat in formation and absorb heat in disintegration, according to the usual rule, are said to be exothermic.

95. The number of heat-units involved in the synthesis of a molecule is to some extent a measure of the stability of the compound. It will require an equal quantity of heat or some form of equivalent energy to disrupt the bonds forged in the heat of chemical union. Water, for example, is one of the more stable molecules, and the heat given off by hydrogen combining with oxygen to form water (that is, the burning of hydrogen in oxygen) amounts to 68,400 units; that is, 2 grams of hydrogen combining with its equivalent weight (16 grams) of oxygen will give off enough heat to raise 68,400 grams of water $1^\circ C$.

96. The effect of high temperature on complex molecules is to weaken the molecular bonds and to favor disruption and a rearrangement of the atoms in new molecules depending on the kind of atoms within the scope of chemical union and their relative affinities for each other under the existing conditions. Heat also weakens the cohesive bonds between molecules, as stated above in connection with changes of physical states of matter.

97. The molecular bonds may be so weakened by the application of heat that the constituents part company. The phenomenon which includes the separation of the constituents of a compound under the influence of heat and their recombination as the temperature falls, by operation of the original chemical affinities which have not at any time been diverted into other relations, is called dissociation. The molecules of elements are sometimes dissociated.

98. When the constituents of a molecule are separated and do not reunite after the disturbing cause has ceased to operate,

having taken up new relations, the phenomenon is termed decomposition.

Fundamental Laws.

99. There are three laws of special importance in chemical science; these are:

1. The Law of Fixed Proportions.
2. The Law of Multiples.
3. The Law of Avogadro.

100. The Law of Fixed Proportions is, that a chemical compound always contains the same elements in the same proportion by weight. For example, pure water contains oxygen and hydrogen and only these two elements, and they are always associated in the proportion of 1.111 pounds of hydrogen to 8.889 pounds of oxygen in every 10 pounds of pure water.

101. The Law of Multiples is, that when two elements unite in several proportions to form several compounds, there will be a regular definite increase of one of the two elements by multiples of the smallest weight of itself entering any of the compounds, for the same weight of the other element in each of the compounds. Thus nitrogen combines with oxygen to form five separate compounds, and the weight of oxygen entering this series increases by multiples of the smallest weight when the same weight of nitrogen is taken in each compound. If we say that the weight of nitrogen shall be 28 pounds in each compound, then the weight of oxygen in the first of the series would be 16 pounds, and it would increase by 16 pounds for each of the subsequent compounds of the series, as follows:

- | | | | |
|----|--------------------|-----------------|------------------------|
| 1. | Nitrogen, 28 lbs.; | oxygen, 16 lbs. | |
| 2. | " | " " | 32 " = 2×16 . |
| 3. | " | " " | 48 " = 3×16 . |
| 4. | " | " " | 64 " = 4×16 . |
| 5. | " | " " | 80 " = 5×16 . |

102. The Law of Avogadro may be stated as follows:

All gases under the same conditions of pressure and temperature have the same number of molecules in equal volumes. That is, a cubic foot of hydrogen will have the same number of molecules as a cubic foot of oxygen, or a cubic foot of the vapor of water, or of the vapor of alcohol, or of any other gas; provided all of these are at the same temperature and subjected to the same pressure.

The law may also be stated as follows: The same number of molecules of all gases occupy equal volumes under the same pressures and temperatures. This law being true of any number of molecules is true of one. If, therefore, we consider the law as applying to the volumes occupied by single molecules, it is evident that the volumes of all single molecules are equal. That is, the space occupied by a single molecule of hydrogen is equal to that occupied by a single molecule of oxygen, or a molecule of water, or a molecule of alcohol. The volumes of all single molecules therefore are equal whether they be elementary or compound.

103. It has been ascertained by experiment that the molecules of most of the elements contain two atoms. Some of the exceptions to this are the following:

Cadmium	}	have but one atom in a molecule.
Mercury		
Zinc		
Phosphorus	}	have four atoms in a molecule.
Arsenic		

For purposes of discussion the conditions existing among diatomic elements only will first be considered.

104. The hydrogen molecule may be taken as the type of diatomic molecules. The space occupied by the molecule, that is the molecular volume, may reasonably be assumed to be equally divided between or occupied by the two hydrogen atoms. The space occupied by one hydrogen atom, that is half the volume of the hydrogen molecule, may be taken as the unit of

volumes; that is, the ultimate standard volume for comparing specific gravities is half the volume of the hydrogen molecule, or the space occupied by the hydrogen atom. The expression, "space occupied by the hydrogen atom," is used for the reason that the atom is supposed not to occupy solidly the limits of the molecule; that is, while it occupies the space of the half-molecule, it does not fill it. Calling such space the atomic space, to distinguish it from the true volume of the atom, *the standard volume may be considered the atomic space of the hydrogen atom.*

105. Since the volumes of all molecules are equal, it may be assumed that the atomic spaces of all diatomic elements are equal. That is, the space occupied by any atom of a diatomic element occupies a space equal to that occupied by the hydrogen atom, and the weights of atoms of diatomic elements are the weights of equal volumes. Keeping in mind the fact that the atomic weight of hydrogen is unity and that the atomic weights of other elements are expressed in terms of this unit, it is evident that the atomic weights of diatomic elements express the relative weights of equal volumes, and if hydrogen be taken as the standard of specific gravity for gases, *the atomic weights of diatomic elements are the specific gravities of these elements in gaseous state referred to hydrogen as a standard.* For example, the specific gravity of oxygen referred to hydrogen is 16, of nitrogen 14, etc., the same as their atomic weights.

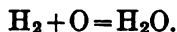
106. For elements whose molecule contain but one atom, that is monatomic elements, the atomic weight represents the matter occupying two "standard volumes" (atomic space of hydrogen atom). The weight of the matter corresponding to one standard volume would therefore be one-half the atomic weight. That is, the specific gravities of monatomic elements in the gaseous state are one-half their atomic weights; e.g., the specific gravity of the vapor of mercury is $\frac{198.5 \text{ (at. wt.)}}{2} =$
99.25.

107. For elements whose atoms occupy one-half the stand-

ard volume, or have four atoms to the molecule, that is tetra-atomic elements, the atomic weight is the weight of matter in a half-volume; therefore, to get the weight of a whole volume, the atomic weight must be multiplied by two. That is, the specific gravities of tetratomic elements are obtained by multiplying atomic weight by two. Thus the atomic weight of phosphorus is 30.7; its specific gravity in gaseous state is $30.7 \times 2 = 61.4$.

108. A compound gas, like marsh-gas (CH_4) or acetylene (C_2H_2), or a compound vapor like water (H_2O) or alcohol ($\text{C}_2\text{H}_6\text{O}$), has as its smallest volume the molecular volume, because by definition the molecule is the smallest quantity that possesses all and only the properties of the substance. Hence the specific gravities of all compound gases are based on the weight of matter in a molecular volume, which is twice the standard volume. Therefore *the specific gravity of all compound gases is obtained by dividing the weight of the molecule by two*. The specific gravity of marsh-gas (CH_4) is $\frac{12+4}{2} = 8$; of water-vapor (H_2O) is $\frac{2+16}{2} = 9$; of alcohol-vapor ($\text{C}_2\text{H}_6\text{O}$) is $\frac{24+6+16}{2} = 23$, etc.

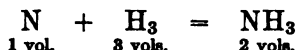
109. A very important principle is based on the fact that the volumes of all molecules are equal. It is this: *Whatever number of elementary or compound gases combine chemically to form a single compound gas, the latter will occupy but two volumes*. Let the reaction for the formation of water be taken as follows:



From paragraph 104 each symbol of an atom of a diatomic element represents a standard volume, provided the symbols stand alone, as in the first member of this equation. That is, in the first member of this equation there are two standard volumes of hydrogen represented, and one standard volume of oxygen, or three standard volumes altogether. When chemical union takes place forming the molecule, water, but one mole-

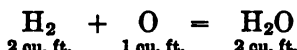
cule is formed, and it cannot occupy more than two standard volumes.

Again, one volume of nitrogen combines with three volumes of hydrogen to form two volumes of ammonia, thus:



This fact, which is based upon the truth of Avogadro's law and is confirmed by experiment, is sometimes referred to as the *principle or law of gaseous condensation*.

110. The examples in paragraph 109 contemplate strictly theoretical standard volumes, that is the spaces occupied by single atoms; but of course such spaces cannot be dealt with in practical work. However, it is axiomatic that what is true of these theoretical volumes will be equally true of any multiple of the volumes, and it follows that the practical standard volume may be assumed as one cubic foot, or one thousand cubic feet, or one litre, or multiple or fraction thereof, and the first reaction of the last paragraph might just as truly have been stated thus:



and the second reaction, thus:



Determination of Atomic Weights.

111. In paragraph 3 it is stated that the atom is the ultimate unit of matter so far as known. It is convenient here to explain how these smallest known quantities of matter have been ascertained. For this purpose the elements may be divided into, first, those which may be volatilized and dealt with in the form of gas or vapor, and, secondly, those which cannot conveniently be so experimented with.

112. The determination of the atomic weights of gaseous elements is based on the principles of the Law of Avogadro and chemical analysis.

Let it be assumed that the atomic weight of hydrogen is desired.

All possible gaseous compounds in which hydrogen enters as a constituent are collected.

(1) According to Avogadro's Law and the deductions therefrom the molecular weights are the weights of equal volumes (all molecular volumes being equal). But the standard theoretical volume is the half-molecular volume. That is, the molecular weights are the weights of double the standard volume, or, in other words, twice the specific gravities of gases, hydrogen being taken as the standard for specific gravity. If, therefore, equal volumes of hydrogen and all its compound gases be weighed under the same conditions of temperature and pressure, and the resulting weights of the compound gases be multiplied by two, the products will be the molecular weights¹ in terms of the weight¹ of the hydrogen atom.

For example, it is known that water contains hydrogen; if a cubic foot of water-vapor be weighed, it will be found to weigh 9 times more than an equal volume of hydrogen under the same pressure and at the same temperature. Multiplying 9 by 2, the product 18 is the weight of the water-molecule; that is, the water-molecule weighs 18 times more than the weight of hydrogen which occupies the atomic space.

¹ The word weights has been used throughout, but it should be kept in mind that quantity of matter, mass, is the exact idea that should be carried along.

In any case $\text{mass} = \frac{\text{weight in pounds}}{\text{acceleration due to gravity at the place}}$, or $m = \frac{w}{g}$. To be correct, we should speak of atomic masses and not atomic weights. The masses are constant, the weights vary with the force of gravity at different latitudes. Atomic weights are expressions for the relative weights of atoms, hydrogen being unity. The weights of all atoms vary with the latitude, but as they all vary according to the same law, their relative weights are as constant as the masses themselves. Therefore no numerical error is introduced by using atomic weights instead of atomic masses.

(2) By chemical analysis the constituents in each one of the compounds may be separated, and the proportion by weight of hydrogen which enters each sample can be found. For example, suppose that the sample of water was 10 pounds. By chemical analysis it can be accurately determined that 1.111 pounds of this was hydrogen gas and 8.889 pounds was oxygen gas. Or, $\frac{11.11+}{100}$ by weight of water consists of hydrogen.

(3) It was ascertained in (1), above, that the molecular weight of water is 18, in terms of the weight of the hydrogen atom. But it now appears that $\frac{11.11+}{100}$ of any mass of water is hydrogen, whether it be a ton or a molecule. Hence $\frac{11.11+}{100}$ of 18 will be the proportional part of hydrogen in the water-molecule, expressed in terms of the weight of the hydrogen atom, or $.1111 \times 18 = 1.999+$, that is 2, and the hydrogen in the water-molecule is represented by H_2 .

(4) Any of the compounds of hydrogen may be dealt with as explained for water. Take hydrochloric acid, for example. Its vapor weighs 18.25 times more than equal volumes of hydrogen, hence, from (1), its molecular weight is 36.5. It may be ascertained by chemical analysis that in every part by weight of hydrochloric acid there are $\frac{2.74}{100}$ parts by weight of hydrogen.

This is as true of a single molecule as of any larger quantity. Hence of the 36.5 units of the molecular weight $36.5 \times .0274 = .999+$ of them are units of hydrogen, that is 1 atom of hydrogen, and the quantity of hydrogen in the molecule of hydrochloric acids is therefore represented by H.

(5) All other compounds of hydrogen may be treated in the same way, and the smallest quantity of hydrogen in terms of the weight of the half-hydrogen molecule may be ascertained.

The data resulting from such a series of experiments may be tabulated as follows:

Hydrogen Compounds.	Specific Grav- ities.	Molecular Weights in Microcriths.	Proportion of Hydrogen.	Weight of Hydrogen in Microcriths. ¹	Symbols.
Water-vapor	9.0	18.0	$.1111 = \frac{2}{18}$	2	H ₂ O
Hydrochloric acid	18.25	36.5	$.0274 = \frac{1}{36.5}$	1	HCl
Hydrobromic acid.	40.5	81.0	$.0123 = \frac{1}{81}$	1	HBr
Sulphydric acid	17.0	34.0	$.0588 = \frac{2}{34}$	2	SH ₂
Ammonia.....	8.5	17.0	$.1765 = \frac{3}{17}$	3	NH ₃
Phosphorus trihydride ...	17.0	34.0	$.0882 = \frac{3}{34}$	3	PH ₃
Marsh-gas.	8.0	16.0	$.25 = \frac{4}{16}$	4	CH ₄
Olefiant gas.	14.0	28.0	$.161 = \frac{4}{28}$	4	C ₂ H ₄
etc.	etc.	etc.	etc.	etc.	etc.

If, in any case, a value less than unity were obtained for this smallest quantity, say $\frac{1}{2}$, that would be taken as the standard atomic weight instead of the one now assumed; if this were made equal to unity, it would necessitate doubling all existing atomic weights. But no weight of hydrogen less than the weight of the half-hydrogen molecule has ever been separated by any procedure or reasoning. The hydrogen atom is, therefore, to be understood to be the smallest quantity of hydrogen that is now known to exist.

(6) All of the compounds of any other *gaseous* element may be analyzed chemically and experimented with physically in the same manner, and the smallest weight of that element which is found in any compound is taken as its atomic weight.

113. The atomic weights of some of the *solid* elements have been determined by a comparative study of the specific heats ²

¹ The weight of the half-hydrogen molecule is often called a *microcrith*.

² The specific heat of a body at any temperature is the ratio of the quantity of heat required to raise the temperature of the body one degree to the quantity of heat required to raise an equal weight of water at its temperature of maximum density (4° C., 39.2° F.) through one degree. The unit of heat is the quantity of heat required to raise the temperature of one pound of water at 39.2° F. one degree.

of the elements in the solid state and a comparison of these specific heats with known atomic weights.

Two investigators, Petit and Dulong, developed the fact that the specific heats of elements are nearly inversely proportional to their atomic weights. That is, the quantity of heat required to raise weights proportional to atomic weights through one degree is practically constant and approximately equal to 6.4 units of heat. This number is called the *atomic heat*. If, therefore, the specific heat of a solid element be determined, and the atomic heat, 6.4, be divided by the specific heat, the quotient will be approximately the atomic weight. To make use of this principle experimentally take any weight of a substance whose atomic weight is known. Using the same source of heat, ascertain the weight of the sample, whose atomic weight is unknown, that must be used in order that the standard sample and the experimental sample shall pass through the same range of temperature in the same time. This weight of the experimental sample will be to the weight of the standard sample as the atomic weight of the former is to the atomic weight of the latter.

Used in conjunction with chemical analysis, the principle of atomic heat will give sufficiently reliable results. For example, by analyzing silver chloride chemically it is found that 108 parts by weight of silver and 35.5 parts of chlorine are obtained. If there be two atoms of silver in this compound its atomic weight is 54; if three atoms, 36; if four, 27; if one, 108. The specific heat of silver at ordinary temperature is .057; the quotient, 112, obtained by dividing 6.4 by .057, suggests that the number 108 should be taken as the true atomic weight, instead of 54, 36, or 27. Chemical analysis is a more exact process than the determination of specific heat, therefore the number 108 is taken in preference to 112.

114. The number of atoms in an elementary molecule is obtained in any case by first ascertaining what the molecular weight is, then the atomic weight, and then dividing the molecular weight by the atomic weight.

Conditions Influencing Affinity.

115. In paragraph 14 it is stated that one property of atoms is that those of one kind have an attraction for certain other kinds. This attractive force is, as already stated, called affinity or chemical affinity. It operates between atoms only. Chemical changes which result in the formation of new substances, by new groupings of the atoms involved, are due to the operation of this force. The intensity of its action varies between different atoms and is modified by different conditions. The quantity of heat evolved in the formation of new substances is, in any given case, to some extent a measure of this intensity, as well as of the stability of the resulting molecules.

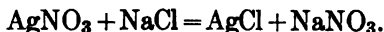
116. There are certain causes and conditions which influence the action of chemical affinity. Among these the following may be enumerated:

Temperature.—Substances that do not combine at one temperature will combine at another; and conversely, through the action of temperature alone, decomposition may be effected. Increase of temperature may cause either a synthetical or an analytical reaction; for example, the synthetical reaction where heat is used in forming metallic oxides, and the analytical reaction where lime is formed from marble by heat.

Solution.—In order to have the force of chemical affinity act, it is necessary that the molecules be very close together. Chemical affinity acts at very short distances only. The form of solution is particularly favorable to the action of chemical affinity. Therefore it is used to get chemical combination where other methods have failed. The objection to a solid form is that the force of cohesion opposes combination by impeding or preventing the mutual penetration and close proximity of the particles of the different substances. In gases cohesion does not interfere with chemical action, but owing to the distance between the particles preventing the necessary close proximity, bodies evince but little disposition to combine when in the gaseous

state and under normal pressure. If any reaction will take place at all, it will take place in the case of solution.

Insolubility.—The principle of insolubility may be stated thus: when two soluble substances, which contain between them the constituents of an insoluble or sparingly soluble substance, are brought together in the form of solutions, the insoluble or less soluble substance is formed and appears in the combined liquids as a suspended solid, called a *precipitate*. For example, if a solution of silver nitrate (AgNO_3) be mixed with a solution of common salt (NaCl), a metathetical reaction will take place, the metals silver and sodium exchanging places in the molecules, forming silver chloride (AgCl) and sodium nitrate (NaNO_3), the former appearing suspended in the resulting liquid as a white curdy precipitate. The reaction would be represented thus:



Volatility.—The principle of volatility may be stated as follows: if two substances contain between them the elements of a volatile substance, and these two substances be mixed and heated together, the volatile substance will be formed and separate as a gas. For example, if pulverized ammonium chloride (NH_4Cl) be mixed with pulverized sodium carbonate (NaCO_3) and the solid mixture heated, the volatile substance ammonium carbonate (NH_4CO_3) will be formed and pass off as a gas, leaving ammonium chloride.

Physical Surroundings.—The atmosphere in which the substance exists has an influence on the reaction which may take place. For example, if FeO be heated in an atmosphere of hydrogen, the O is taken away from the Fe and passes off in combination with hydrogen as H_2O , water-vapor. Retaining the same heat and simply reversing the process, forcing the H_2O over the Fe , FeO will be reproduced and hydrogen set free. The atmosphere is thus seen to have an effect on chemical affinity.

Nascent State.—By nascent state is meant the state of the element or substance just in the act of being separated in

chemical decomposition. The nascent state is particularly favorable to chemical combination. Reactions which will not otherwise take place may take place at the instant that atoms are freed from the bonds that have held them in a molecule.

Pressure.—The retarding influence of pressure is seen in such cases as the action of acids on metals, or the electrolysis of water in sealed tubes. In these cases the elimination of a gas is an essential condition of the change, and this being prevented, the action is retarded. On the other hand, there are numerous reactions which are greatly promoted by increased pressure—those, namely, which depend on the solution of gases in liquids, or on the prolonged contact of substances which under ordinary pressure would be volatilized by heat.

Stoichiometry.

117. Stoichiometry is that part of chemistry which deals with the computations of the weights of substances used in chemical reactions and resulting therefrom, and in the volumes of gases connected therewith. The foregoing principles may be applied, now, in the solution of chemical problems involving weights and gaseous volumes.

118. It has been seen that symbols represent atoms; that the atoms have definite weights for each element, and that the weight of the molecule of any substance is the sum of the weights of the atoms which compose the molecule.

It may now be stated that the symbols may be used not only to represent atomic weights of the elements, but of any weights proportional to atomic weights. In stoichiometry they are so used. That is, to the abstract numbers in the second column of the table on pages 3 and 4 the name of any unit of weight may be applied, such as grams, ounces, pounds, tons.

A reaction that is true for the atomic weights proper is equally true *if the same proportions by weight be observed, using any unit of weight.*

For example: one atom of oxygen unites with two atoms of hydrogen to make water. Since the weight of the oxygen atom is 16 and the hydrogen atom 1, it follows that *any weights whatever of oxygen and hydrogen in the proportions of 16 to 2 will produce 18 parts by weight of water*. That is, 16 lbs. of oxygen will unite with 2 lbs. of hydrogen to make 18 lbs. of water. The reaction being $O + H_2 = H_2O$, and any unit of

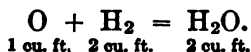


weight may be applied to the numbers written below the symbols.

In the same way any reaction may be utilized to solve problems involving weights.

119. Reactions may also be used to solve problems relating to volumes of gases, and these problems are often of value in dealing with explosives.

The symbols of the atoms may be considered to represent the atomic spaces as well as atomic weights, it being kept in mind that the ultimate standard volume for the comparison of gases is the space occupied by the half-molecule, and that all single molecules, whether simple or compound, have equal volumes. These principles were enunciated in paragraphs 102 and 109, and it was seen in the latter paragraph that *one* volume of water united with *two* volumes of hydrogen to make *two* volumes of water-vapor, or that, giving concrete values to the volumes, one cubic foot of oxygen will combine with two cubic feet of hydrogen to make two cubic feet of water-vapor, considering all gases at the same temperature and pressure. Expressed in connection with the reaction, this may be written



In the same way, any reaction involving gases may be made use of to write out the volume relations existing among the reagents in the first member of the equation and the products in the second member. If any solids appear in the reaction they are not, of course, to be considered in these volume relations.

120. In solving problems in stoichiometry, it will be useful to keep certain units and numbers in mind; among these may be enumerated the following:

1 cubic foot of hydrogen at 60° F. and 30 inches barometer weighs about 37 grains; at 0° C., 40 grains.

1 pound of hydrogen under same temperature and pressure occupies about 189 cubic feet.

1 gram = 15.43 grains.

1 litre = 61.02 cu. inches = 1.76 pints.

1 gram of hydrogen at 0° C. and 760 mm. barometer occupies 11.16 litres.

Volumes of gases change with temperature as follows, if pressure remain constant:

$\frac{1}{519.4}$ of volume at 60° F. for each degree F.

$\frac{1}{273}$ of volume at 0° C. for each degree C.

If volume remains constant, pressures change according to these same ratios.

The ratio giving the rate of change in terms of volume at any other temperature than 60° F. or 0° C. may be obtained from the denominators of the fractions given for 60° F. and 0° C., by adding the number of degrees of higher temperature or subtracting the number of degrees of lower temperature. For example, the ratio for volume at 0° F. would be $\frac{1}{519.4 - 60} =$

$\frac{1}{459.4}$, and for 20° C. would be $\frac{1}{273 + 20} = \frac{1}{293}$.

PROBLEMS.

1. To find the relative weights of the constituents in any quantity of a compound, as, for instance, H_2O , it is seen that in this formula the constituents of the compound are in the proportion, by weight, of 16 to 2. It makes no difference whether we deal with a single molecule or a ton of water, this same

relation obtains. In the first case the unit is the microcrith, in the second, the unit is the pound. If required, therefore, to find the number of pounds of hydrogen to make a ton of water, we have this proportion:

$$2:18::x:2000 \text{ pounds.}$$

2. To find the percentage composition of a substance, given the molecular formula. Let us take, for example, cellulose:



The following form will be found convenient in solving such problems:

	Atomic weights.	No. of atoms.	Total weights.	Per cent.
C ₆	12	6	72	$\frac{72}{162} = 44.4$
H ₁₀	1	10	10	$\frac{10}{162} = 6.2$
O ₅	16	5	$\frac{80}{162}$	$\frac{80}{162} = 49.4$

3. To find the empirical formula of a substance, given the percentage composition and atomic weights. The empirical formula is the simplest expression for the numerical relations of the atoms as determined by analysis, and this is directly connected with the percentage composition. It is found by first determining by analysis the percentage composition of a substance and then dividing each percentage by the atomic weight. For example, take cellulose as in the last problem:

$$\begin{aligned} \text{Per cent.} & \quad \text{Atomic weights.} \\ \text{C} &= 44.4 \div 12 = 3.7 \\ \text{H} &= 6.2 \div 1 = 6.2 \\ \text{O} &= 49.4 \div 16 = 3.08 \end{aligned}$$

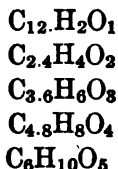
If we wish to express a numerical relation between the atoms in cellulose, we can use the proportional numbers thus: $C_{3.7}$, $H_{6.2}$, $O_{3.08}$, these numbers being proportional to the true numbers of atoms; dividing through by the smallest number, 3.08, we get



This is the empirical formula, the simplest expression for the numerical relations existing among the atoms of a molecule of cellulose.

4. To find the molecular formula, having the empirical formula and the molecular weight. First find, as above, the empirical formula, then arrange a series of formulas that are multiples of the empirical formula and select that formula which gives the proper molecular weight.

Thus, assume the empirical formula $C_{1.2}H_2O_1$ and the molecular weight = 162. Required, the molecular formula. Write out the following multiple series:

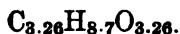


Computation will show that the formula $C_6H_{10}O_5$ only gives the proper molecular weight, hence this is the molecular formula. It is to be kept in mind also that in case of a fractional result, the formula which is nearest the given molecular weight is taken, and the nearest whole number of atoms is taken in writing out the molecular formula.

5. By chemical analysis 460 grains of a certain substance whose molecular weight is 92 gave the following results: C = 180 gr. H = 40 gr., O = 240 gr.—total 460 gr. Required the percentage composition, empirical formula, and molecular formula of the substance.

We have:

	%		At. Wt.		Numerical Relation of Atoms.
C.....	39.13	÷	12	=	3.26
H.....	8.7	÷	1	=	8.7
O.....	52.17	÷	16	=	3.26
	<hr/>				
	100				



∴ Empirical formula = $\text{C}_1\text{H}_{2.67}\text{O}_1$.

∴ Molecular formula = $\text{C}_3\text{H}_8\text{O}_3$.

6. Since the atomic weights of substances represent not only the actual weights of atoms but also the weight of quantities proportional thereto, if we fix on the weight of any one element, all the others are fixed by that act. For example, (a) take the reaction $\text{Cu} + \text{O} = \text{CuO}$. Assume 5 grains of copper.

Then $63.2:16::5:x$ ∴ $x = 1.26$ grains of O. The atomic weights of Cu and O being 63.2 and 16 respectively, x gives the weight of O in grains.

$$63.2 + 16 = 79.2.$$

Then $63.2:79.2::5:x$ ∴ $x = 6.26$ grains of CuO.

(b) Take the reaction $\text{CaCO}_3 + \text{heat} = \text{CaO} + \text{CO}_2$. Assume 30 pounds of CaCO_3 . The weights of the resulting products would be found as follows:

$$\text{CaO} = 40 + 16 = 56 = \text{mol. wt.}$$

$$\text{CO}_2 = 12 + 32 = 44 = \quad "$$

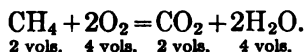
$$\text{CaCO}_3 = \quad \quad \quad 100 = \quad "$$

$$100:56::30:x, \text{ giving } 16.8 \text{ pounds CaO}$$

$$100:44::30:x, \quad " \quad 13.2 \quad " \quad \text{CO}_2.$$

7. As all molecules occupy two volumes, we can from inspection of a chemical equation readily determine the number of molecules, and from these the volumes of the gaseous reagents or products.

Take CH_4 . It is a combustible gas (marsh-gas). Both C and H unite with O in burning. C will burn to CO_2 , and for this we must have 2 atoms of O. H_4 will burn to H_2O , and for this we must also have 2 atoms of O. In order, therefore, to burn CH_4 we must supply it with 4 atoms of O. -We may therefore write:



These volumes may refer to any unit of volume. For example, assume 20 cubic feet of CH_4 . The problem would then be, How many cubic feet of O are required to burn 20 cubic feet of CH_4 ? We have, $2:4::20:x$ $\therefore x=40$ cubic feet.

Again, take the reaction, $\text{N} + \text{H}_3 = \text{NH}_3$. Note that the
 $\begin{array}{ccc} 1 \text{ vol.} & 3 \text{ vols.} & 2 \text{ vols.} \end{array}$
 sums of the volumes in the two members of the equation do not have to balance; the sums of the weights on both sides of the equality sign must, however, always balance.

8. In order to pass from weights to volumes, we have the following relation:

$$\frac{\text{Wt. of gas}}{\text{Wt. of unit vol.}} = \text{volume}$$

(usually 1 cubic foot)

Therefore weight of gas = volume in cubic feet \times weight of 1 cubic foot of gas.

9. To find the specific gravity and weight of a cubic foot of a *mixture* of gases; for example, atmospheric air.

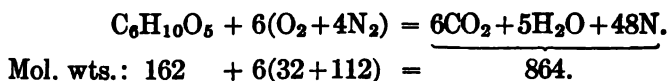
Assume the weight of 1 cubic foot of H (barometer 30", thermometer 0° centigrade) = 40 grains.

Any given weight or volume of air consists approximately of

$$\begin{array}{r} \text{O}_2 + 4\text{N}_2 \\ \hline \begin{array}{cc} 2 \text{ vols.} & 8 \text{ vols.} \end{array} \\ \hline 10 \text{ vols.} \\ \text{O}_2 = 16 \times 2 = 32 \\ 4\text{N}_2 = 14 \times 8 = 112 \\ \hline 144 \end{array}$$

$$\begin{aligned}\therefore \text{Wt. 1 vol. air} &= \frac{1}{10} \text{ of } 144 = 14.4 = \text{specific gravity} \\ \text{" 1 cubic foot H} &= 40 \text{ gr.} \\ \therefore \text{" 1 " " air} &= 576 \text{ gr.}\end{aligned}$$

10. To find the number of cubic feet of air that will be required to burn 100 pounds of wood. Assume wood to have the molecular formula $\text{C}_6\text{H}_{10}\text{O}_5$ and the reaction of combustion to be as follows:



It therefore takes 864 pounds of air to burn 162 pounds wood.

How much will it take to burn 100 pounds?

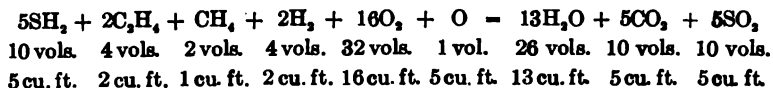
$$162:864::100:x. \quad \therefore x=533.9 \text{ pounds.}$$

To reduce to cubic feet: 7000 gr. = 1 pound.

$$1 \text{ cu. ft. air} = 576 \text{ gr.} \quad \frac{576 \times 533.9}{576} \text{ grs.}$$

$$6488 \text{ cu. ft.}$$

11. Assume that the following represents the reaction involved in the burning of illuminating-gas. If there be in this group of mixed gases 2 cubic feet of hydrogen, what are the other volumes?



Since there are 2 cubic feet of hydrogen and 2H_2 parts of hydrogen, that is, 4 standard volumes, one standard volume in this case is $\frac{2 \text{ cubic feet}}{4} = 0.5 \text{ cubic feet.}$ Multiply each number of

"vols." by 0.5 cubic feet and we have the volume of each gas in cubic feet, as shown below each molecular formula.

12. a. Find the percentage of iron in limonite or brown hæmatite, $2\text{Fe}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$.

$$2\text{Fe}_2 = 56 \times 4 = 224$$

$$2\text{O}_3 = 16 \times 6 = 96$$

$$3\text{H}_2 = 1 \times 6 = 6$$

$$3\text{O} = 16 \times 3 = 48$$

$$\text{Mol. wt.} = 374$$

From which the per cent of Fe is found to be 59.9.

b. Same for hæmatite or specular iron ore, Fe_2O_3 .

$$\text{Fe}_2 = 56 \times 2 = 112$$

$$\text{O}_3 = 16 \times 3 = 48$$

$$\text{Mol. wt.} = 160$$

From which the per cent of Fe is found to be 70.

c. Same for magnetite or magnetic oxide, Fe_3O_4 .

$$\text{Fe}_3 = 56 \times 3 = 168$$

$$\text{O}_4 = 16 \times 4 = 64$$

$$232$$

From which the per cent of Fe is found to be 72.4.

d. Same for spathic, clay ironstone, or blackband, FeCO_3 .

$$\text{Fe} = 56 \times 1 = 56$$

$$\text{C} = 12 \times 1 = 12$$

$$\text{O}_3 = 16 \times 3 = 48$$

$$116$$

From which the per cent of Fe is found to be 48.3.

e. Same for iron pyrites, FeS_2 .

$$\text{Fe} = 56 \times 1 = 56$$

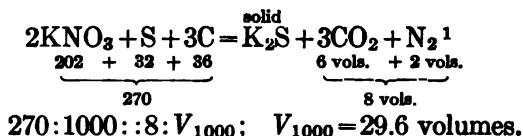
$$\text{S}_2 = 32 \times 2 = 64$$

$$120$$

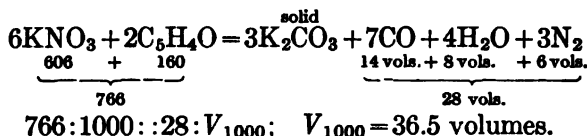
From which the per cent of Fe is found to be 46.7.

13. The celebrated Russian chemist Mendeléeff has suggested a method of comparing explosives by finding the number of volumes in the explosive reaction corresponding to 1000 parts by weight; this volume is indicated by the symbol V_{1000} . The effect of the temperature of the explosion is not considered.

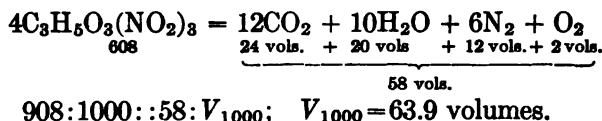
a. Determine Mendeléeff's relation of V_{1000} in the following reaction for black gunpowder:



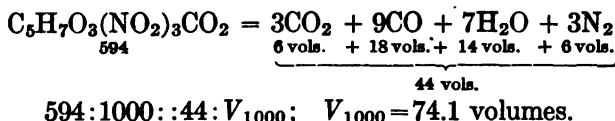
b. Same for brown gunpowder:



c. Same for nitroglycerine:

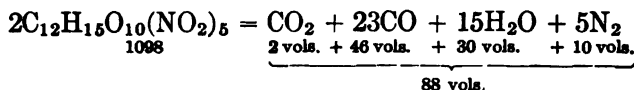


d. Same for guncotton:



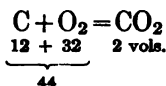
e. Same for smokeless powder; nitrocellulose having 12.75 per cent of nitrogen, N, which is about the percentage in smokeless powder for cannon in the United States:

¹ The numbers under the reagents (first members of the equations) are *molecular weights*, those under the products (second members of the equations) are *volumes*.



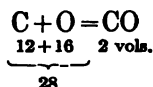
$$1098:1000::88:V_{1000}; \quad V_{1000}=80.1 \text{ volumes.}$$

f. Same for C burned with sufficient supply of O:



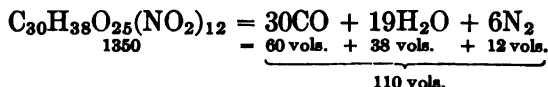
$$44:1000::2:V_{1000}; \quad V_{1000}=45.5 \text{ volumes.}$$

g. Same for C burned with insufficient supply of oxygen:



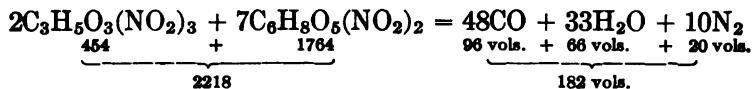
$$28:1000::2:V_{1000}; \quad V_{1000}=71.4 \text{ volumes.}$$

h. A comparison of the values of V_{1000} in *f* and *g* is important because on this basis depends the whole argument of Mendeléeff as to the desirability of so arranging this percentage of C, H, O, and N in nitrocellulose as to have all the C burn to CO. When this is done, we get the reaction for Mendeléeff's pyrocellulose, which is nitrocellulose containing 12.44% of nitrogen:



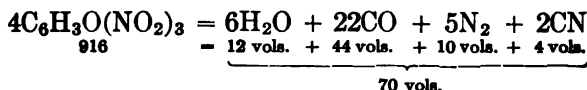
$$1350:1000::110:V_{1000}; \quad V_{1000}=81.5 \text{ volumes.}$$

i. Same for cordite (used in our service in Armstrong guns); mixture nitroglycerine and nitrocellulose:



$$2218:1000::182:V_{1000}; \quad V_{1000}=82 \text{ volumes.}$$

j. Same for picric acid, used in shell (lyddite, melinite, etc.):



$$916:1000::70:V_{1000}; \quad V_{1000}=76.4 \text{ volumes.}$$

GENERAL PROPERTIES OF IMPORTANT SUBSTANCES.

The following general properties of important substances may be committed to memory with advantage, preparatory to laboratory work:

The *nitrates* are all soluble in water.

The *dichlorides* are soluble in water, except that of lead.

The *monochlorides* are soluble in water, except those of silver and mercury.

The *sulphates* are soluble in water, except that of calcium, which is but slightly soluble, and that of barium, strontium, and lead, which are insoluble.

The *sulphates* are insoluble in alcohol.

The *carbonates* are insoluble in water, except those of the alkalis; they are all soluble in water containing CO_2 in solution, i.e., carbonated water.

The *carbonates*, except those of the alkalies, are decomposed by heat (CO_2 passing off).

The *carbonates* are decomposed by sulphuric, hydrochloric, and nitric acid, with evolution of CO_2 and effervescence.

The *chlorates* are soluble in water.

The *acetates* are soluble in water.

The *oxides* are insoluble in water, except those of the alkalies and barium, which are soluble; those of the alkaline-earth metals, except barium, are slightly soluble.

The *sulphides* are insoluble in water, except those of the alkalies and alkaline earths.

The *hydroxides* are insoluble in water, except those of the alkalies and alkaline-earth metals, the latter being but slightly soluble.

The *phosphates* are insoluble in water, except those of the alkalies.

II.

SUBSTANCES USED IN THE MANUFACTURE OF EXPLOSIVES.

BEFORE treating directly of explosives proper, it will be advantageous to consider apart the substances used in their manufacture.

Regarded from the point of their composition, explosives may be divided into two classes, namely:

1. Explosive mixtures.
2. Explosive compounds.

The former consist of an intimate mixture of distinct substances, properly prepared and conglomerated mechanically in varying proportions to meet the requirements of different demands. Each particle of such explosive mixtures must have at least a particle of some oxygen-supplier, such as a nitrate or chlorate, and some combustible, such as carbon or sulphur. The old black and brown powders and the new explosive called ammonal are typical examples of such mechanical mixtures. The characteristic quality of such explosives is that the nature of the explosion may be graded by varying the proportions of the ingredients.

The latter class consist of substances whose molecules contain within themselves the oxygen and carbon and hydrogen necessary for combustion. Any substance whose molecule contains oxygen, carbon, and hydrogen in the proportions to give CO , or CO_2 and H_2O , may become an explosive. One which is so constituted and at the same time has weak molecular bonds due to the presence of the radical NO_2 or other weak-binding radical is an explosive compound. The

characteristic quality of this class of explosives is that the elements constituting the explosive are always present in the molecule in the same quantities, according to the law of fixed proportions, and the nature of the explosion cannot be graded by varying the quantities of the constituent elements, as in the case of mechanical mixtures.

The substances used in the manufacture of these two classes of explosives may be considered conveniently in the following order:

1. The nitrates and chlorates, used as oxygen-suppliers in explosive mixtures.
2. The combustibles, charcoal and sulphur, used in explosive mixtures.
3. The hydrocarbons and other compounds of organic origin used in the manufacture of high explosives, and of the more recently developed nitro-powders. This includes hydrocarbons proper, alcohol, ether, acetone, phenol, glycerine, cellulose, and certain nitro-derivatives of some of these, including the nitrobenzines, nitronaphthalene, nitrophenol.

Potassium Nitrate, (KNO_3). Nitre. Saltpetre.

This salt is found in nature as an incrustation on the surface of certain soils in hot countries. It results in such instances from the decomposition of organic matter in the presence of moist alkaline earths. The decomposition of both animal and vegetable matter produces ammonia; the oxidation of ammonia in nature appears to be furthered by the growth of certain low forms of vegetable life; this combines with the atmospheric oxygen, yielding nitric acid, and this, in turn, acts on other potassium salts to produce the nitrate; the solution evaporating at the surface leaves the solid as an incrustation.

It may be produced artificially by the nitre-bed process. Vegetable and animal matter are piled together in large heaps, with limestone, old mortar, wood ashes, and any alkaline material, on an impervious floor protected from the weather.

One side is made nearly vertical and this side is exposed to the prevailing wind; the opposite side is cut into terraces. Urine from stables and other sources is poured over the terraces, which have a slight pitch toward the body of the heap, with a small gutter cut at the inner junction of the step with the body of the heap. The temperature is kept at 60° to 70° F. The liquid seeps through the mass, and the chemical action described above takes place in the body of the heap; the soluble nitrates percolating through the heap finally reach the vertical side exposed to the wind, and evaporation occurring there leaves on this surface an incrustation of nitrate mixed with other salts.

The nitre coming from these sources is known as *crude*. An analysis of crude saltpetre from India gave the following: potassium chloride, 0.84; sodium chloride, 0.20; insoluble, 0.21; water, 1.35. The crude nitre from the beds contains in addition, as a rule, chlorides of calcium, magnesium, and ammonium. Crude nitre must be refined before using in explosives. The chlorides are separated from the nitre by dissolving the mass in hot water. The nitre crystallizes first in cooling and is skimmed off. The chlorides remaining in solution are converted into nitre by mixing with solution of potassium carbonate.

It is important that nitre used for explosives should contain no chlorides because of their hygroscopic properties. A sample should therefore always be subjected to the standard test for chloride. The sample solution should be tested also with barium chloride or nitrate for any sulphate, and with ammonium oxalate for lime.

Nitre is distinguishable by the form of its crystals (long striated or grooved six-sided prisms), and by its deflagration when heated on charcoal. It fuses at 635° F. (335° C.) to a colorless liquid which solidifies on cooling to a translucent crystalline mass. Heated to red heat it effervesces from the escape of oxygen and becomes reduced to the nitrite (KNO_2). If heated beyond this, the nitrite is decomposed, leaving a mixture of K_2O and K_2O_2 .

Its value in explosives is due to the fact that it acts as a

supplier of oxygen to the combustible element present. Five-sixths of its oxygen is available for combination with any combustible, the nitrogen coming from its decomposition being given off in the free state. The reaction for the decomposition of nitre by charcoal may be represented as follows:



Owing to the concentrated form in which the oxygen is presented to the carbon by nitre, carbon burning to CO_2 or CO gives a much higher temperature than in ordinary combustion where the O is supplied by the air.

The specific gravity of nitre is 2.07 compared with water. Since one cubic inch of water weighs 252.5 grains, one cubic inch of nitre weighs ($252.5 \times 2.07 =$) 523 grains.

Write $2\text{NO}_3\text{K} = \text{N}_2\text{O}_5\text{OK}_2$.

The five atoms of oxygen of the N_2O_5 only are available for combustion; that is, in 202 grains (weight proportional to the weights of two molecules) of nitre there are 80 grains of oxygen free to unite with a combustible. Since one cubic inch of nitre weighs 523 grains, it will contain ($523:202::x:80$) 207 grains of oxygen available for combustion, and since 16 grains of oxygen gas has a volume of 46.7 cubic inches at 60°F . and 30" barometer, the 207 grains of oxygen in one cubic inch of solid nitre will be equivalent to 607 cubic inches of oxygen gas at 60°F . and 30" barometer. And since there is but one volume of oxygen in five volumes of air ($4\text{N} + \text{O}$), we arrive at the result that one cubic inch of nitre contains as much oxygen as is found in 3000 cubic inches of air at 60°F . and 30" barometer.

It is this fact that causes the high temperature of explosives of black gunpowder. The nitre presents the oxygen to the charcoal and sulphur in concentrated and pure form, and the reaction between the minute particles of the mixture takes place at each point in a very short time. All of the nitrates that are used in explosives are, like nitre, oxygen-carriers.

Almost all of the nitre now used in the manufacture of gun-

powder is obtained by the conversion of sodium nitrate into potassium nitrate by means of potassium chloride. When sodium nitrate and potassium chloride are mixed and the solution boiled down, sodium chloride is deposited and potassium nitrate remains in the boiling liquid, the reaction being $\text{NaNO}_3 + \text{KCl} = \text{KNO}_3 + \text{NaCl}$.

The potassium chloride required for this conversion is obtained from the refuse of the sugar-beet root, and from certain salt deposits, notably the salt-mines of Stassfurt, Saxony; also from sea-salt, seaweed; the mineral carnallite is a double chloride of potassium and magnesium.

**Sodium Nitrate, (NaNO_3). Peruvian or Chile Saltpetre.
Cubical Saltpetre.**

This salt is found in large beds beneath the surface of the soil in the provinces of Atacama and Tarrapaca, Chile. It occurs at depths of from one to five yards, and in strata from two to twelve feet thick. The mined earth contains from fifteen to sixty-five per cent of sodium nitrate and a large quantity of other salts, such as sulphates, chromates, chlorates, iodates, borates, etc.

The crude nitrate is extracted from the earth by a process of boiling and crystallization. As thus obtained it contains about one or one and a half per cent of impurities, chiefly sodium chloride and sodium sulphate.

The sodium-nitrate crystal is different from that of potassium nitrate; the former being a rhombohedron, the latter a six-sided prism.

Sodium nitrate is more hygroscopic than potassium nitrate, and on this account cannot be used with advantage in the manufacture of explosives, unless the explosive be kept absolutely protected from the air. As mentioned under potassium nitrate, its chief value in connection with explosives is as a source from which potassium nitrate may be obtained by chem-

ical reaction. It is also used in the manufacture of nitric acid.¹

Ammonium Nitrate, (NH_4NO_3) .

This salt has properties resembling in a general way those of the two nitrates just considered. It was formerly looked upon with favor as an oxygen-carrier in explosives on account of the fact that the basic part, NH_4 , on explosion, gave free gases instead of solids. Its excessive hygroscopic properties, however, have eliminated it from use, except in a few special explosives which are so prepared as to be protected against the action of the air. It is used in certain blasting-powders and dynamites with a view to reducing the temperature of the explosion, the weak affinity of the element nitrogen for other products of explosion causing a comparatively low temperature of explosion; dissociation of the products also favors a lower temperature.

The "fire-damp" gas (marsh-gas, CH_4) is explosive when

¹ It is estimated that, at the present rate of consumption, the Chilian saltpetre beds will be exhausted in about thirty years. This fact has caused a revival of the old process of producing nitrates and nitric acid by the oxidation of the nitrogen of the air. Over one hundred years ago Cavendish observed that the electric spark would oxidize the nitrogen of the air, which is composed of about 79 parts of nitrogen by volume and 21 parts of oxygen. It is only recently, however, and in the face of the prospective disappearance of natural sources, that this fact has been considered of use in a commercial way. A plant has been installed at Notodden, Norway, where nitrate of calcium is being manufactured, applying the Cavendish principle. Air is forced at a carefully regulated rate through a disk of electric arcs. The high temperature of the arcs causes the oxidation, but unless removed speedily from this temperature the nitrogen oxide is decomposed by the same heat. By forcing the air through the disk its movement is so regulated *that at a certain velocity the oxide is not reduced*, and is conducted on to a tower down which milk of lime is made to trickle, and this latter absorbs the nitrogen oxide. The electricity used at Notodden is generated by water-turbines. About 75,000 litres of air are passed through the plant per minute. Each unit produces about 325 tons of calcium nitrate per year, the chemical equivalent of 250 tons of nitric acid, 100 per cent, or 337 tons of nitrate of sodium. The total capacity of the Notodden plant, three units at present, is equivalent to about 1000 tons of Chilian saltpetre per year.

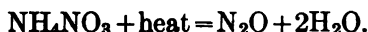
mixed with two volumes of oxygen or ten volumes of air. This mixture ignites at about 2200° C. The temperature of explosion of most explosives is above this; therefore, when used in mines, they may serve to ignite the fire-damp.

Good types of these so-called "safety" explosives are the Favier Explosives. P. A. Favier of Paris suggests the following safety mixture:

Favier No. 1—Ammonium nitrate. 88 per cent.
Dinitronaphthalene. 12 per cent.

The nitrate is dried in a steam-heated tube, pounded in a heated mortar, and, while still heated, sprinkled with melted dinitronaphthalene, pressed into cylinders, dipped in melted paraffin, and wrapped in paraffined paper.

When exposed to gentle heat, ammonium nitrate melts at 150° C., boils at 210° C., and disappears in the form of steam and nitrous oxide:



It deflagrates if heated suddenly to a high temperature, as by throwing it on a red-hot surface. If very carefully heated it may be sublimed.

Interest has lately been revived in this substance by the fact that it is an ingredient in the new explosive, "ammonal." This explosive consists essentially of ammonium nitrate and pulverulent metallic aluminum, the latter being prepared by a special process. Some potassium nitrate and charcoal are also present in varying proportions in different grades of ammonal.

The chief claim for ammonal is that the aluminum protects the ammonium nitrate from moisture and thus eliminates the objection heretofore held against its excessive hygroscopic properties.

Ammonal has given excellent results as a charge for shell and for disruptive purposes. As a mechanical mixture it possesses the insensitiveness of this class of explosives. It must,

however, prove itself to be a thoroughly stable mixture when stored for long periods of time under the conditions to be found in ordinary service and storage magazines. It is too new and untried an explosive, as yet, to merit a place among standard military explosives.

Barium Nitrate.

Of all the metallic nitrates used in explosives, barium nitrate is least hygroscopic. It is, on this account, used in some cases instead of KNO_3 . It is much heavier than the other alkaline and alkaline-earth nitrates.

It is found in nature as the mineral witherite. Artificially it is produced by dissolving the carbonate in dilute nitric acid.

It is decomposed by heat, leaving the oxide of barium and giving off oxygen with some form of nitrogen oxide, depending on the degree of temperature used.

It is an ingredient in some of the modern military and sporting smokeless powders.

Its rate of combustion is slower, its temperature of ignition higher, and the quantity of free oxygen available is less than for potassium nitrate.

The per cent of oxygen in the several nitrates just considered is given in the following table:

Sodium nitrate.....	56.47% NaNO_3 .
Ammonium nitrate.....	60.00% NH_4NO_3 .
Potassium nitrate.....	27.49% KNO_3 .
Barium nitrate.....	36.78% $\text{Ba}(\text{NO}_3)_2$.

Of the 60% of oxygen in ammonium nitrate only 20% is available as free oxygen, 80% being required for combination with hydrogen to form water, as shown by the molecular formula when written thus: $\text{N}_2\text{O}(\text{H}_2\text{O})_2$.

Although barium nitrate gives the lowest percentage of O by weight, by *volume* it gives about the same as nitrate of sodium on account of its high specific gravity.

The Chlorates.

The chlorates are oxygen-carriers like the nitrates. They act more readily as oxidizers and at lower temperatures. Indeed they part with their oxygen so readily that the heat of even ordinary friction will cause the union of their oxygen with a combustible.¹ This is favored in the case of potassium chlorate by the fact that its molecule gives off heat in breaking up. At high temperatures the chlorates act violently on all combustible substances. Potassium chlorate is the oxidizing ingredient in signal and pyrotechnic compositions, being usually mixed with sulphur and some metallic compound to give the color desired to the flame. The following combinations may be given:

Red Fire—(1) 40 grains strontium nitrate thoroughly dried over a lamp are mixed with 10 grains of potassium chlorate and reduced to the finest powder. *In another mortar* 13 grains of sulphur are mixed with 4 grains of black sulphide of antimony. The two powders are then placed upon a sheet of paper and very intimately mixed with a bone-knife, avoiding great pressure.

(2) Another prescription: Charcoal 1 part, shellac 2 parts, sulphur 8 parts, potassium chlorate 12 parts, strontium nitrate 40 parts.

Blue Fire.—Potassium chlorate 15 parts, potassium nitrate 10 parts, oxide of copper 30 parts; mix in mortar; transfer mixture to paper and mix with a bone-knife with sulphur 15 parts.

Green Fire.—Barium chlorate 10 parts, barium nitrate 10 parts; mix in mortar; transfer to paper; mix these with sulphur 12 parts.

A composition of friction-primers for cannon consists of twelve parts of potassium chlorate, twelve parts of sulphide of

¹ A mixture of pulverized potassium chlorate and sulphide of antimony explodes if struck with a hammer. A grain or two of potassium chlorate rubbed in a mortar with a little sulphur will explode.

antimony, and one part of sulphur worked into a paste with a solution of an ounce of shellac in a pint of grain alcohol.

The explosive used in fire-crackers is a mixture of potassium chlorate and lead ferrocyanide.

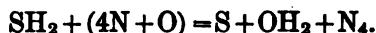
All mixtures of chlorates with combustible substances are liable to spontaneous combustion.

Sulphur, S.

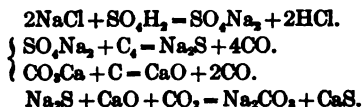
Sulphur is found in the uncombined state in nature in certain volcanic districts. It is found in the combined state especially in the sulphide ores of many metals, and in some mineral waters as hydrogen sulphide. Among the ores may be mentioned iron pyrites (FeS), copper pyrites (CuFeS₂), galena (PbS), blende (ZnS), crude antimony (Sb₂S₃), cinnabar (HgS). Also with oxygen and the metals as sulphates, such as gypsum (CaSO₄.2H₂O), heavy spar (BaSO₄), Epsom salts (MgSO₄.7H₂O), Glauber's salts (Na₂SO₄.10H₂O).

Sulphur is obtained from native veins in volcanic districts. It is obtained also by reduction from the sulphides (either the ores or the tank-waste residue of alkali works).

The process of getting sulphur from the alkali works is known as the Chance-Claus process. Calcium sulphide was formerly a useless by-product in the making of sodium carbonate.¹ Now it is a paying by-product. The calcium sulphide waste is mixed with water, stirred into a paste, and run into large cast-iron vessels (carbonizers); through this mass CO₂ is forced. The effect of heat, moisture, and CO₂ is to form CaCO₃ and liberate SH₂. The SH₂ is passed into a gas-holder, where it is mixed with air and burned:



¹ The production of CaS in the alkali works is as follows:



The sulphur obtained by the Chance-Claus process is of great purity and requires no refining.

Native sulphur obtained from the veins is purified by direct distillation and subsequent refining to free it of earthy impurities. The same process is followed in obtaining sulphur from iron and copper pyrites.

The refining process is conducted in large retorts connected with a subliming chamber and distilling tank; it consists of melting down the crude sulphur and distilling it from the molten state.

In refining crude sulphur, whether from native sulphur or the pyrites ores, a charge of seven hundred pounds, or over, of the crude sulphur is put in a large cast-iron retort. A fire is started under the retort. The sulphur will begin to melt at 239° F. This will be evidenced by the appearance of a light yellow vapor above the mass. The vapor of sulphur rises and passes into a subliming-chamber, where it is condensed and falls as "flowers of sulphur." When the temperature of the mass is about 560° F., red fumes will be observed in the retort. Distillation then takes place instead of sublimation. The vapor of sulphur now passes over into a condensing-tank which is cooled by circulating cold water, and it is condensed as a thick yellow liquid. The sulphur which first passes over is known as *sublimed sulphur* or *flowers of sulphur*; it is not used for making gunpowder, as it sometimes contains a small percentage of foreign substances; it is returned to the retort for reworking. That which is distilled over at the higher temperature is known as *distilled* or *roll sulphur*; it is this that is used in the manufacture of gunpowder.

As an ingredient of gunpowder, sulphur is valuable on account of the low temperature (500° F.) at which it ignites, thus facilitating the ignition of the mixture; its combination with the oxygen of the nitre gives also a higher temperature than would obtain if charcoal alone were used; this higher temperature has the effect of increasing the rate of combustion and pressure of the gases evolved.

Heat has an extraordinary effect on the physical condition of sulphur. If a quantity of sulphur be placed in a glass flask and heated, the following changes will be observed:

At about 120° C. it is a pale yellow, limpid liquid. As the temperature rises from 120° C. the color grows darker and the liquid more viscous until, at 180° C., it is nearly black and opaque, and so viscous that the flask may be inverted without spilling the sulphur. At this point the temperature remains constant, although the application of heat continues, showing changes taking place within the molecular structure of the sulphur. On continuing the heat, the sulphur becomes liquid again at 260° C., though not so mobile as at first. At 444° C. it boils and is converted into a brownish-red, very heavy vapor, and an explosion often takes place between the red vapor and the air.

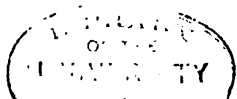
If the flask be now removed from the flame and decanted into water, the sulphur will descend through the water in the form of a brown, soft, elastic, rubber-like string. If a portion be allowed to remain in the flask and to cool therein, it will pass successively through the same states as described above in the inverse order, becoming black and viscous at 180° C., and a pale-yellow thin liquid at 120° C.; if it now again be poured into cold water, it will descend through it in small button-like drops of ordinary sulphur. As the portion still left in the flask cools it will deposit small tufts of crystals, and finally solidify into a yellow crystalline mass.

The brown, rubber-like sulphur after a few hours will become yellow and brittle; the change is accelerated by gentle heat and is attended with an evolution of the heat made latent at the 180° C. stage.

The *roll sulphur*, or *distilled sulphur*, used in the manufacture of powder is always easily soluble in carbon disulphide; the flowers of sulphur only partially so.

Charcoal. Carbon. C.

Carbon is the combustible element of most explosive mixtures, and it is present in combination with hydrogen in most explosive compounds. Its function in all cases is to combine



with oxygen, producing either CO or CO₂, the heat resulting from this chemical reaction causing increased volume of the gases produced.

In black gunpowder and other mechanical mixtures the carbon is supplied in the form of pulverized charcoal. The charcoal used in the manufacture of powder is obtained by the destructive distillation of certain woods and woody fibres, such as willow, alder, dogwood, and rye straw; the lighter woods being used because they give a charcoal more easily combustible than the heavier ones.

The charring is done in a metallic cylinder placed in a retort over a furnace-fire. The effect of the heat is to drive off the volatile parts of the wood; these pass off for the most part in the form of wood naphtha (CH₄O), pyroligneous acid (C₂H₄O₂), carbon dioxide, carbon monoxide, and water, leaving a residue containing from 70 to 85 per cent of carbon, associated with small quantities of hydrogen (5% to 3%), oxygen (23% to 10%), and ash (about 2%) consisting of the carbonates of K, Ca, Mg, calcium phosphate, potassium sulphate and silicate, sodium chloride, oxides of Fe and Mg.

The wood consists of sticks about $\frac{1}{2}$ to $\frac{3}{4}$ of an inch in diameter, cut into short lengths. It is cut when in full sap, in the spring of the year, is stripped of its bark, and dried for a considerable time either in the open air or in hot-air drying-chamber. Charcoal that is charred in cylinders is called *cylinder* charcoal, to distinguish it from the common *pit* charcoal.

After charring, the charcoal is kept for about two weeks exposed to the air; it is then ready for grinding for powder-making. If ground at once after charring, there is danger of spontaneous combustion from combination with oxygen of air.

The charring process takes from 2½ to 3½ hours; its completion is known by the blue flame of CO burning to CO₂ at the mouth of the pipe which conducts the volatile products of distillation from the retort to the flame of the furnace under the retort. The charred wood weighs about 30% of its original weight.

If charred at temperatures above 400° C., the product is not sufficiently friable. At very high temperatures, 1000° to 1500° C., the charcoal is very hard, dense, and rings with a metallic sound.

The temperature of ignition varies directly with the temperature of charring. Charcoal that has been charred at 260° to 280° C. will ignite at from 340° to 360° C.; that made at 290° to 350° C., at from 360° to 370° C.; that at 432° C., at about 400° C.; that at 1000° to 1500° C., at 600° to 800° C.

If mixed with sulphur, it ignites at lower temperatures; that made at temperatures under 400° C. mixed with powdered sulphur will ignite at 250° C. If the charcoal has been made at higher temperatures, the sulphur burns, leaving the charcoal unchanged.

The capacity of charcoal to decompose the nitrates varies in the same way. Charcoal made at temperatures between 270° and 400° C. will combine with saltpetre at 400° C.; if made at temperatures of 1000° to 1500° C., it combines only when heated to redness.

Freshly made charcoal has remarkable powers to absorb certain gases into its pores. One cubic inch of charcoal will absorb 100 cubic inches of ammonia oxygen gas, 50 cubic inches of sulphuretted-hydrogen gas, 10 cubic inches of oxygen, and 7 cubic inches of water-vapor. This is purely a mechanical effect, but the intimate association of such gases in the mass of charcoal in time develops chemical action and leads to spontaneous combustion. Freshly prepared charcoal, pulverized and stored in that form, will ignite spontaneously if the mass is over two feet deep. The ignition begins at the bottom or near the bottom. Samples thus treated have ignited in 36 hours.

The property of freshly made charcoal to absorb gases is made use of in deodorizing sewers, cesspools, etc.

The charcoal used in the manufacture of brown powder is made from rye straw. The straw is carefully selected, only the large, firm, perfect stalks being taken. The charring is done by superheated steam at a relatively low temperature. The

charcoal contains about 48 per cent of carbon, 5.5 per cent of hydrogen, 45 per cent of oxygen, 1.5 per cent of ash.

Compounds of Organic Origin.¹

Most of the recently developed explosives, whether used for propulsion or disruptive effects, are derived from organic substances. Substances of organic origin are also used in their manufacture. It therefore becomes necessary to present some of the more simple relations existing among these substances and to define certain general terms.

The organic substances enumerated below may be regarded as the most important ones in connection with explosives.

1. *The Hydrocarbons.*—Compounds of C and H only, in various modes of grouping, starting with the saturated hydrocarbon, C_nH_{2n+2} , the isologous series down to C_nH_{2n-6} , with their derivatives constitute the fatty group, because many of them exist in fats; the C_nH_{2n-6} group and its derivatives constitute the aromatic group, because many are obtained from balsams, essential oils, gum resins, etc. The physical state of a hydrocarbon may generally be known from the number of C atoms present in its molecular formula. If there be 4 or less, the substance is gaseous; if more than 4 and less than 12, it is liquid; if more than 12, solid. Most hydrocarbons are obtained by the fractional distillation of organic substances and are volatile; they have characteristic odors, are insoluble in water, soluble in alcohol, ether, and carbon disulphide.

¹ The following organic radicals should be noted:

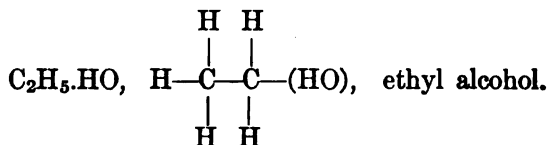
(HO)'	occurring in alcohols and phenols, called	<i>hydroxyl.</i>
(CO)'	" " ketones,	" <i>carbonyl.</i>
(CO.HO)'	" " acids,	" <i>carboxyl.</i>
(CH ₂)'	" " wood-alcohol derivatives,	" <i>methyl.</i>
(C ₂ H ₅)'	" " grain " "	" <i>ethyl.</i>
(C ₆ H ₅)'	" " benzine derivatives,	" <i>phenyl.</i>
(CH ₃ CO)'	" " acetic " "	" <i>acetyl.</i>
(NO ₂)'	" " nitro-compounds,	" <i>nitryl.</i>

The ending "yl" indicates an unsaturated radical; the unsatisfied valency units are indicated by the marks to the right and above the parentheses inclosing the radicals.

The most important of the hydrocarbon series in explosives are:

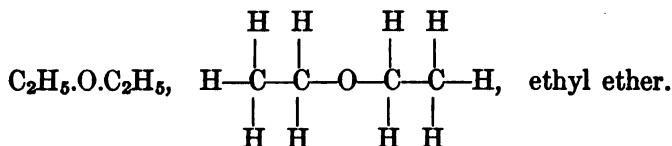
- (a) *The Paraffins*.—General formula C_nH_{2n+2} , in which n represents any whole number. They are derived from the fractional distillation of mineral oil.
- (b) *The Olefins*.—General formula C_nH_{2n} , in which n represents any whole number not less than 2. They are found in the products of distillation of coal, wood, etc.
- (c) *The Acetylenes*.—General formula C_nH_{2n-2} , in which n represents any whole number not less than 2. The first member of this series, acetylene, C_2H_2 , is formed by the direct union of carbon and hydrogen under the influence of high temperature. The molecule is endothermic, 61,100 units of heat being absorbed in its formation. It is the only hydrocarbon that has been formed by direct union of its elements. The acetylenes are found in the products of distillation of all substances rich in carbon and hydrogen.
- (d) *The Benzines*.—General formula C_nH_{2n-6} , in which n represents any whole number not less than 6. The hydrocarbons of this series are extracted from the coal-tar obtained by the distillation of coal in manufacturing illuminating-gas.

2. *The Alcohols*.—From their chemical behavior they may be considered as hydroxides of the paraffin hydrocarbons, and represented by the general formula $C_nH_{2n+2-x}(HO)_x$, in which n represents any whole number, and x any whole number not greater than n . Example:



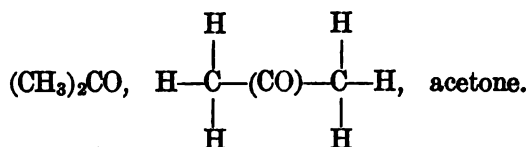
3. *The Ethers*.—They may be regarded as derived from the alcohols by the replacement of one or more atoms of hydrogen

of the hydroxyl radicals of alcohols by a univalent paraffin hydrocarbon radical. Example:



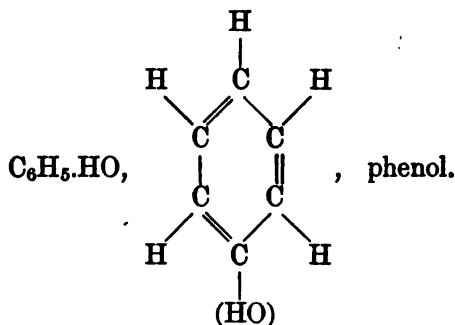
They may also be regarded as the oxides of the paraffin hydrocarbons. Under this conception, the molecular formula for ethyl ether would be written $(\text{C}_2\text{H}_5)_2\text{O}$.

4. *The Ketones*.—They may be regarded as combinations of hydrocarbon radicals of the paraffin series with carbonyl (CO). Example:

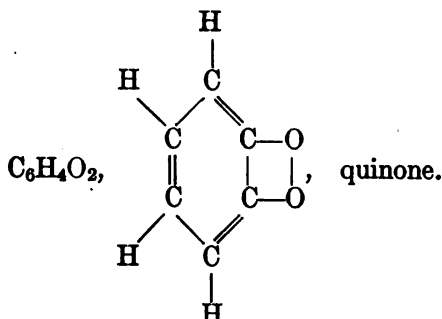


5. *The Phenyls*.—They are derived from benzine (C_6H_6) by substituting hydroxyl (HO) for one or more atoms of hydrogen.

Example: .



6. *The Quinones*.—They may be considered derived from benzene by substituting two oxygen atoms for two hydrogen atoms. Example:



7. *The Carbohydrates.*—These are combinations of six atoms of carbon, or some multiple of six, with some multiple of the water group (H_2O). Example: $C_6(H_2O)_5$, cellulose.

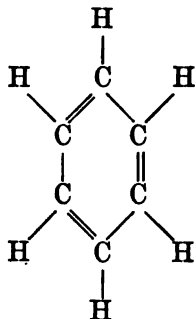
The Benzine Series.

Benzine itself (C_6H_6) is not used as an explosive, but lately certain of its derivatives have come into prominence as disruptive explosives, particularly as charges for shell.

The chief source of benzine is coal-tar. In the distillation of coal-tar, that portion of the distillate which passes over between 79° and 82° C. consists chiefly of benzine; it is purified by cooling below 0° C., at which temperature it solidifies and the lighter hydrocarbons then may be squeezed out by pressure. It boils at 80° C. It is insoluble in water, soluble in ether, acetone, chloroform, and alcohol. It is a solvent for fats and india-rubber, resin, sulphur, essential oils. It is inflammable, burning with a smoky flame. It is very volatile and its vapor is heavier than air. This vapor mixed with a certain proportion of air is explosive. These facts make it necessary to be careful about exposing benzine to evaporation in laboratory or elsewhere. The lower stratum of air in a room may be heavily charged with benzine vapor and the odor of it not be detected by a person standing. It has a strong characteristic odor.

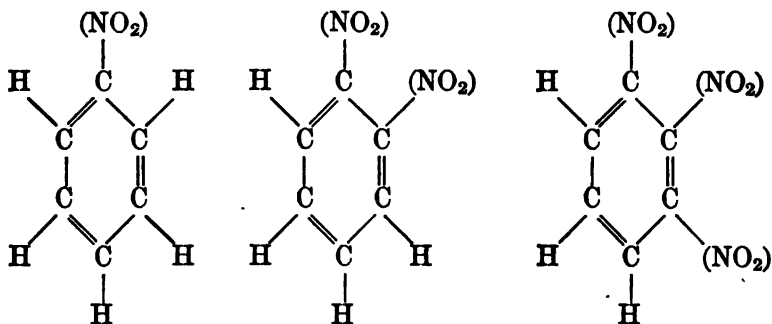
Nitric acid acts upon it, converting it into nitrobenzine.

The structural formula of benzine may be written as follows:



The action of nitric acid is to substitute one or more nitryl groups (NO_2) for one or more atoms of hydrogen, giving rise to the following molecular relations:

$\text{C}_6\text{H}_5.\text{NO}_2$, $\text{C}_6\text{H}_4.(\text{NO}_2)_2$, $\text{C}_6\text{H}_3.(\text{NO}_2)_3$; or, structurally,



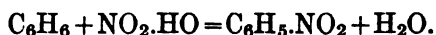
Mononitrobenzine. Nitrobenzine. Mirbane Oil,
 $\text{C}_6\text{H}_5(\text{NO}_2)$.

This substance is produced by adding one part of benzine to three parts of a mixture of nitric acid (sp. gr. 1.40) and sulphuric acid (sp. gr. 1.84), this mixture being made up of 40 parts of the former to 60 parts of the latter.

The benzine is added gradually, avoiding too violent chem-

ical action. The heat due to this action must not be allowed to rise too high, the reaction being conducted in running water.

Mononitrobenzine may be made also by dropping benzine into the strongest nitric acid, or into a mixture of equal volumes of ordinary nitric acid and sulphuric acid. A violent chemical action results, giving rise to red fumes and the liquid becomes red. On pouring the liquid into several times its volume of water, a heavy oily liquid falls, which is mononitrobenzine. The reaction is



The red fumes result from a secondary reaction not represented.

The sulphuric acid if used is present merely to maintain the nitric acid at efficient strength by combining with the water formed; it undergoes no resultant chemical change.

When the chemical action ceases the mixture is allowed to cool. The nitrobenzine will be found floating on the top of the waste acids. The latter are separated from the former by a siphon. The liquid remaining is "purified" of free acid by washing with water containing a small quantity of sodium carbonate. In order to avoid the formation of dinitrobenzine, an excess of benzine must be used in the process. A certain quantity of unnitrated benzine, therefore, remains mixed with the nitrated product. These are separated from each other by a process of vaporization, benzine volatilizing at 80° C., and mononitrobenzine not until 205° C.

Mononitrobenzine has the characteristic odor of almonds. It is sold commercially as mirbane oil, which consists of the substance dissolved in alcohol. In this form it is used in perfumery and as a flavoring in confectionery. It is poisonous in large doses both as a vapor and a liquid. It is only slightly soluble in water. It dissolves readily in alcohol, benzine, and concentrated nitric acid.

Cold mononitrobenzine dissolves nitrocellulose, reducing it to a pasty or jelly-like mass. Indurite, a smokeless powder

invented by Professor C. E. Munroe, consists of guncotton freed of the lower nitrocellulose by treatment with methyl alcohol and mixed with mononitrobenzine (9 to 18 parts of nitrobenzine to 10 of guncotton). Suitable oxidizing salts may be added. The mixture is then treated with hot water or steam, which has the effect of hardening it to the consistency of bone or ivory, hence its name.

Mononitrobenzine is not explosive alone, but, under the application of heat, decomposes with evolution of nitrous fumes.

If heated to a high temperature in the presence of oxygen, as when a small amount is placed on a red-hot iron plate, it will detonate.

Ignited in the open air, it burns with a reddish smoky flame, owing to the fact that the oxygen of the air does not, under these conditions, combine with the freed carbon. If mixed with explosive substances, such as guncotton, nitroglycerine, etc., the mixture may be detonated by a suitable fulminate of mercury primer.

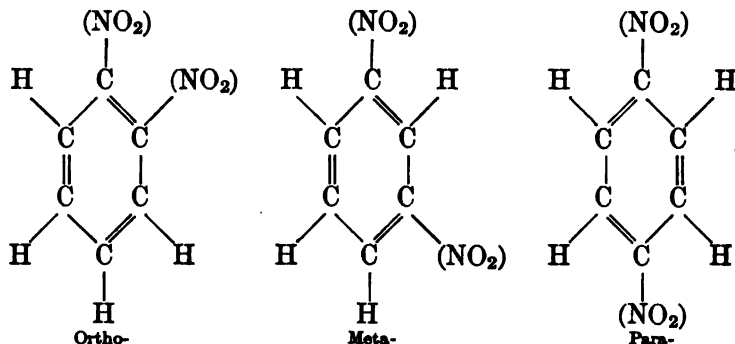
Mixed with nitroglycerine it serves to lower the freezing-point of that explosive.

Mixed with potassium chlorate it forms the explosive known as rackarock.

Dinitrobenzine, $C_6H_4(NO_2)_2$.

There are three dinitrobenzine isomers having the same molecular formula but having different physical characteristics, viz.: meta- melts at $89^\circ C.$, ortho- at $118^\circ C.$, para- at $172^\circ C.$

The dinitrobenzine molecule may be represented as follows, illustrating the principle of isomerides, having the same number of atoms in a molecule and the same elements, but possessing different physical properties, due to the different structural arrangement of the atoms within the molecule.



The theory is, that when adjacent atoms are displaced one substance is produced; when alternate, another; and when opposite atoms, still another. That is, the benzene ring of six carbon atoms may give rise to the three isomerides.

Dinitrobenzene is made as explained for mononitrobenzene, except that the acid mixture is maintained at boiling temperature. On cooling, a yellowish crystalline solid separates from the liquid in long brilliant prisms. This solid is a mixture of the three dinitroisomerides with the *meta*- predominating.

It is soluble in warm water and alcohol, and like the monocompound is poisonous.

Heated in open air it melts, and if the temperature be raised it ignites and burns with a smoky flame.

When mixed with oxidizing substances it forms an explosive. In this way it is an ingredient of many modern explosives (see Cundill's Dictionary of Explosives).

Trinitrobenzene, $\text{C}_6\text{H}_3(\text{NO}_2)_3$.

This explosive is prepared by treating metadinitrobenzene with concentrated nitric acid and fuming Nordhausen sulphuric acid.

While the substance possesses possibilities of use as an ingredient of explosives, little use has been made of it up to the present time.

Naphthalene, $C_{10}H_8$.

This substance is a transparent crystalline solid having the characteristic odor of coal-gas.

Its chief source is coal-tar. In the fractional distillation of coal-tar it passes over when the temperature rises just above $200^{\circ}C$.

When coal-tar is distilled the benzine hydrocarbons first pass over, constituting what is known as *light oil*. As the temperature rises, a heavier yellow oil, heavier than water, passes over. This is known as *dead oil*; it is much more in quantity than the light oil, amounting to about one-fourth of the bulk of the tar; it contains those constituents which have a high specific gravity and high boiling-point. As the temperature of the distillation gets above $200^{\circ}C$., a solid is formed in the distillate as it cools; this is crystalline naphthalene. It is separated from the liquid by pressure. It is freed from the heavier products by sublimation. If heated gently at about $200^{\circ}C$., it sublimes over and may be collected in the form of small transparent white crystals.

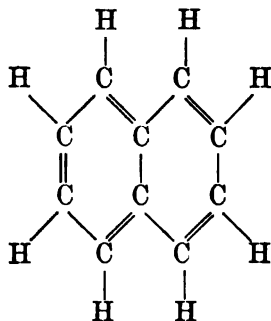
It is inflammable, burning in air with a smoky flame.

It is insoluble in water; soluble in alcohol, ether, and benzine.

In its chemical relations it is closely allied to benzine.

The substitution products derived from naphthalene have many isomerides, depending on which atoms of hydrogen are displaced.

Its relation to benzine is illustrated by its structural formula, which is written as follows:



The nitro-substitution products are more numerous, as a matter of course, than those of benzine, since there are a greater number of hydrogen atoms available for replacement by the nitryl radical (NO_2).

While this substance is not explosive alone, some of its derivatives are susceptible of forming explosives, and the many possibilities presented by a study of its derivatives marks it as one of the most promising organic substances in connection with further developments of explosives.

Mononitronaphthalene, $\text{C}_{10}\text{H}_7(\text{NO}_2)$.

Pulverized naphthalene is added to a mixture of four parts of nitric acid (sp. gr. 1.40) and five parts of sulphuric acid (sp. gr. 1.84). The naphthalene is added little by little and constantly stirred. The temperature of the mixture is kept so that it does not fall below 160°F ., in order that the nitronaphthalene formed will not solidify. When the nitration is completed the charge is run off into lead-lined tanks, wherein the mononitronaphthalene crystallizes out. It is separated by pressure from the waste acids, washed in hot water, then granulated in cold water and washed until all trace of free acid is removed.

It melts at 61°C ., and crystallizes from the fused state in needle-like yellow crystals. It is only slightly volatile when warmed or heated by steam.

It is insoluble in water; soluble in alcohol, ether, benzine, carbon disulphide.

If heated above 300°C ., it decomposes.

It is not explosive alone, but in connection with oxygen-carriers may become explosive, as, for example, in the Favier explosives of France, in which it is associated with ammonium nitrate.

Dinitronaphthalene, $C_{10}H_6(NO_2)_2$.

This is made from the mononitronaphthalene by heating it with cold concentrated nitric acid, or from the unnitrated naphthalene by nitrating at boiling-heat until entirely dissolved, using the strongest acid, or a mixture of a weaker nitric acid (1 part) with sulphuric acid (2 parts).

It is a bright-yellow crystalline solid, the crystals forming in long slender needles.

It melts at $185^{\circ}C$. It is insoluble in water, slightly soluble in ether and in alcohol, less so in carbon disulphide and cold nitric acid. It is readily soluble in hot xylene, benzene, acetic acid, and turpentine.

If crystallized from its solution in acetic acid, it appears to take the form of an isomeride having a melting-point of $216^{\circ}C$.

It is chiefly used in the "safety" explosives in association with ammonium nitrate.

Trinitro- and tetranitro-naphthalene may be formed by repeated nitration of dinitronaphthalene at higher temperatures. While possibly available as ingredients of explosives, associated with oxygen-carriers, little use has as yet been made of them.

Phenol, $C_6H_5(OH)$. Carbolic Acid.

Also called *phenic acid*, *hydroxybenzine*, *benzine hydroxide* and *monohydrate of benzine*.

It results from the oxidation of benzine.

Its chief source is coal-tar. It passes over in the fractional distillation of coal-tar between 150° and $200^{\circ}C$. It forms a part of the "heavy oil" in this process. After the distillation of heavy oil is allowed to cool and the naphthalene has crystallized out and been separated, the remaining liquid is treated with caustic soda and stirred. On standing, two layers of liquids are observed. The upper layer consists of the higher

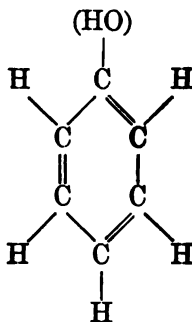
hydrocarbons of the benzene series, the lower of a solution of sodium phenylate. This is acted upon by sulphuric acid and purified by further fractional distillation: The *phenol* distils over at between 180° and 190° C.; from the distillate it crystallizes out on cooling in needle-like crystals.

It fuses at 42° C.; boils at 182° C.; is soluble in 15 parts of cold water; readily soluble in ether and alcohol. 198 parts by weight combine with 18 parts by weight of water, when heated together, forming the aquate $(C_6H_2HO)_2Aq$, which forms on cooling six-sided prisms; the aquate fuses at 16° C. and is readily soluble in water. The commercial phenol is usually the aquate and soon becomes liquid when the bottle is placed in warm water. Once fused it has a tendency to remain in that state, but solidifies suddenly if the cork is removed.

It blisters the skin and is very poisonous.

It is used as an antiseptic and to arrest fermentation and putrefaction.

Its structural formula is:¹



Phenols combine more readily with alkalis than alcohols do, and this property gave rise originally to the designation "acid" used with it. It may be deoxidized by passing its vapor over heated zinc-dust, $C_6H_2(HO) + Zn = C_6H_6 + ZnO$.

Certain compounds of phenol are used as color tests for acids and alkalis.

¹ Benzene forms other hydroxides, including dihydroxides $C_6H_4(HO)_2$, and the trihydroxide $C_6H_3(HO)_3$, pyrogallol.

The aqueous solution of phenol gives the following color indications:

With ferric chloride: purple-blue.

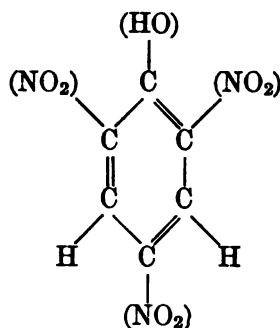
With ammonium hydroxide and calcium chloride: blue.

With mercury dissolved in nitric acid: yellow precipitate. The yellow precipitate dissolves with *dark-red color* in *nitric acid*.

The most important of its color-test compounds is *Phenolphthalein*. This is used in the manufacture of all nitro-explosives to test for the presence of the salts of sodium or potassium, the presence of the carbonates or hydroxides of these metals being indicated by a red color. If a carbonate is tested, it should be in *boiling* solution, driving off free CO_2 , as *free* CO_2 will neutralize the test, phenolphthalein giving no color in excess of CO_2 .

Picric Acid, $(\text{C}_6\text{H}_2.\text{HO}(\text{NO}_2)_3)$. Trinitrophenol.

Its structural formula is:



When phenol is treated with nitric acid it may form three nitrates, namely: mononitrophenol ($\text{C}_6\text{H}_4.\text{HO}.\text{NO}_2$), the dinitrophenol ($\text{C}_6\text{H}_3.\text{HO}(\text{NO}_2)_2$), and the trinitrophenol. The last only has, as yet, found application in explosives. It recently has found use not only as an explosive itself, but more particularly as an ingredient of special explosive mixtures. It and its salts (the picrates) find application in detonating or disruptive explosives only. Most of the new so-called "shell-filler"

explosives are either picric acid, mixtures with it or derivatives thereof. Among these may be mentioned *Ecrasite*, Austrian; *Lyddite*, English; *Mellinite*, French; *Shimose*, Japanese; Abel's picric powder and Brugère's powder (nitre and picrate of ammonium); one form of Rackarock (nitrobenzene and picric acid).

MANUFACTURE OF PICRIC ACID.

Equal quantities by weight of concentrated H_2SO_4 and phenol are mixed in an iron vessel, stirred and heated by steam to from 212° to 250° F. From time to time tests are made to see if the phenol-sulphonic acid formed is soluble in cold water. When this is so the mixture is allowed to cool and twice the quantity of water is added.

The nitration then takes place in earthen vessels standing in running water which can be heated by steam-pipes. Three parts by weight of nitric acid is placed in these receivers and one part of the sulphonic solution is added. The latter is allowed to run in gradually, as at first the reaction is violent. Afterwards it becomes sluggish and then steam is turned on and the temperature of the solution raised to restore the chemical action.

The picric acid formed separates at first as a sirupy liquid and becomes crystalline on cooling. It is separated from the mother-liquor in a centrifugal machine, and is washed in the same machine with pure warm water. The crystals are further purified by redissolving in warm water, recrystallizing, and finally drying at 95° F.

The reactions of the process are:



Picric acid has an extraordinarily bitter taste.

It always gives an acid reaction.

It is sparingly soluble in cold water; it dissolves in hot water, giving a bright-yellow color to a large volume of water.

It dissolves readily in alcohol. Its solution stains the skin and other organic matter yellow and is used in dyeing for this purpose. It is one of the few acids which form sparingly soluble potassium salts. A cold aqueous solution of picric acid is an excellent test for any soluble potassium salt, giving, when added, a yellow, adherent, crystalline precipitate of potassium picrate. This salt in the solid state and dry is very sensitive, exploding with violence if heated or struck.

Considerable diversity of opinion has existed as to whether picric acid is explosive if subjected to simple heating. There is no doubt that it is less explosive than nitroglycerine and gun-cotton. If a small mass is heated in a capsule or flask, it melts and gives off vapors which ignite and burn without causing an explosion. A very small quantity may be sublimed if carefully heated in a glass tube. It is a mistake, however, to think that picric acid is incapable of explosion by simple heating. If it is heated to a high temperature, it decomposes with disengagement of heat, developing a process of oxidation. When a decomposition liberates heat, its rapidity increases with the pressure or confinement for a given temperature, or with the temperature for a given pressure; in the latter case, the decomposition increases very rapidly. This principle suggests that picric acid would explode if either the temperature or pressure of its environment should increase, and still more rapidly if both temperature and pressure increased together: this is the condition existing when it is heated in a closed space.

Picric acid may, in accordance with these principles, be made to detonate if heated very suddenly to a high temperature in an open vessel at the ordinary pressure, especially if the vessel be heated itself beforehand, so that there is little loss of heat by conduction.

If a glass tube 25 to 30 mm. long be heated to redness

and one or two small particles of picric acid be thrown into it, they will explode before they can vaporize. If the mass be considerably increased, the walls of the tube may be sufficiently cooled by the mass of the picric acid to modify or destroy entirely the explosive effect.

Similar experiments may be conducted with mononitrobenzene, dinitrobenzene, mono-, di-, and tri-nitronaphthalene.

The nature of the decomposition, whether explosive or non-explosive, and the degree thereof depend on the temperature of the enclosure, the temperature and mass of the explosive used.

If, however, a large mass of an explosive, like any of those just named, were to ignite in a closed space, its decomposition would generate more and more heat, the temperature would rise higher and higher, and the phenomenon might cause a detonation at some particular point, and the explosive wave there started might be transmitted throughout a very large mass.

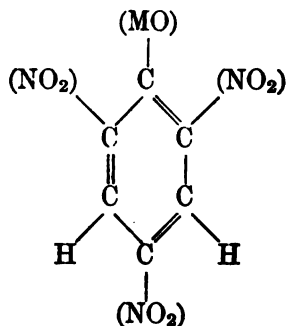
In 1887 a disastrous explosion of picric acid took place in the chemical works of Messrs. Roberts, Dale & Company, at Manchester, England. An investigation at that time, and experiments since made, have revealed the fact that if picric acid is in contact with some metals or the oxides or nitrates of some metals, such as lead, iron, strontium, potassium, it is quite likely that very sensitive explosive salts may be formed. Litharge, the oxide of lead, particularly, has a tendency to form very sensitive compounds if in contact with picric acid, and may cause the detonation of a large mass of it.

Many accidents have resulted in handling shells charged with lyddite which are presumed to have been due to the formation of such sensitive compounds.

For these reasons red or white lead should not be used to seal the screw-threads of shell-plugs when the shells are filled with picric acid or derivatives thereof.

Picrates, $C_6H_2(NO_2)_3.MO$. (In which M represents some metal radical.)

Structural formula:



For many years attempts have been made to use the picrates of certain metals as ingredients of explosives. In 1869 a class of powders were introduced in France, known as Designolle's Powders, consisting of picrate of potassium, nitre, and charcoal. Potassium picrate is, however, too sensitive to give a serviceable explosive. About the same time, Brugère in France and Abel in England suggested the use of ammonium picrate instead of potassium picrate. These powders gave excellent results.

Brugère's powder contained:

Picrate of ammonium.....	54 parts
Nitre.....	46 "

It was stable, safe to manufacture, burned with slower rate than black powder, was less hygroscopic, had little smoke, small residue, did not attack metals. In the small-arm rifle it gave about $2\frac{1}{2}$ times the effect of black powder.

Abel's powder was practically the same, the proportion being 60 parts of ammonium picrate to 40 of nitre.

Ammonium picrate appears to be the only picrate which has given satisfactory results. While the metallic picrates are very sensitive to shock, ammonium picrate is quite insensitive. It is also very stable, showing no tendency to form ammonium nitrate in the above mixtures.

It is easily made by saturating a hot solution of picric acid with a concentrated solution of ammonium hydroxide, or by passing ammonia-gas through a hot solution of picric acid. As soon as the solution is completely saturated with the new salt it is allowed to cool, when ammonium picrate separates in the form of long yellow prisms.

If ignited, it burns without any tendency to explosion.

It is insensitive to shock of any kind, and can be detonated only by a very powerful primer.

Alcohols, Ethers, Ketones.

Alcohols and alcohol derivatives are used either in the manufacture or as ingredients of modern explosives.

The alcohols may be regarded as formed from the hydrocarbons of the paraffin series by substituting the radical HO for one or more of the hydrogen atoms. They are, therefore, as already indicated, properly organic hydroxides of the paraffin series. Some authorities consider all hydroxides of the hydrocarbons as alcohols, there being a series of alcohols corresponding to each series of hydrocarbons.

Alcohols containing (HO) are monohydric;

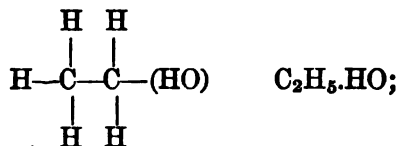
“ “ (HO)₂ “ dihydric;

“ “ (HO)₃ “ trihydric;

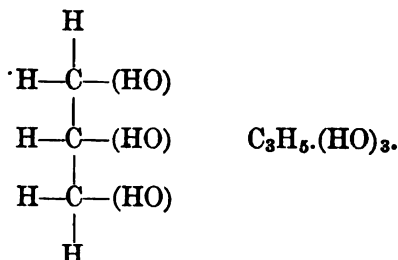
“ “ etc. “ etc.

There are but two alcohols proper which need be described in connection with substances used in explosives, namely, monohydric ethyl alcohol, $C_2H_5.HO$, and trihydric propenyl alcohol (glycerine), $C_3H_5(HO)_3$.

The structural formula of ethyl alcohol is

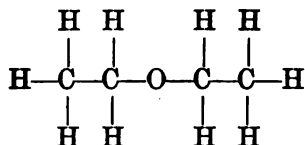


of glycerine:

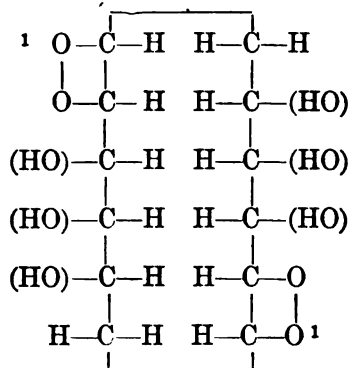


Two other substances may be referred to here as allied in structure to the alcohols, in order to emphasize both the relation existing and the differences in structure.

1. *Ethyl ether*, which, as before explained, is the oxide of the paraffin hydrocarbon radical, C_2H_5 . Its molecular formula is $(\text{C}_2\text{H}_5)_2\text{O}$ and its structural formula is



2. *Cellulose*.—This has a more complex structure. It does not fall strictly under the alcohols or ethers, but its chemical behavior leads to its classification as a hexhydric alcohol. Under this conception its structural formula, using a double grouping, may be written as follows:



¹ Quinone arrangement suggested by Dr. John W. Mallet, University of Virginia. See Walke's Lectures on Explosives, p. 205.

Another hydrocarbon derivative closely allied to the foregoing is acetone or dimethyl ketone ($\text{CH}_3\text{CO.CH}_3$). The relation is as follows:

Acetic acid results from the oxidation of alcohol:



Acetone may be considered as derived from acetic acid by displacing the HO group by a paraffin hydrocarbon radical, thus:

acetic acid: $\text{CH}_3.\text{CO.HO}$; acetone: $\text{CH}_3.\text{CO.CH}_3$.

Acetone is the standard solvent for highly nitrated celluloses used in smokeless powders containing nitroglycerine, and ordinary guncotton for demolitions, etc.

A mixture of ethyl alcohol, $(\text{C}_2\text{H}_5)\text{HO}$, and ethyl ether, $(\text{C}_2\text{H}_5)_2\text{O}$, in the proportion by volume of 1 to 2 is used in dissolving nitrocellulose of medium nitration in the manufacture of smokeless powders that are made of pure nitrocellulose without an admixture of nitroglycerine.

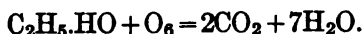
Ethyl Alcohol. Vinic Alcohol. Alcohol. $\text{C}_2\text{H}_5.\text{HO}$.

When mixed with water known as spirits of wine.

As stated above this substance is one of the ingredients of the solvent used in colloidizing nitrocellulose in making smokeless powder.

It is a colorless liquid having a characteristic odor and burning taste.

Pure or "absolute" alcohol has a specific gravity of 0.794 at 15°C . It freezes at -130.5°C . Its boiling-point is 78.3°C . It burns with a blue smokeless flame, the reaction of combustion being as follows:



It evaporates rapidly in the open air without combining with oxygen. Exposed to the air it absorbs water. Bottles containing it should therefore be tightly corked. It mixes

with water in all proportions, evolving little heat and giving a mixture rather smaller in volume than the sum of the volumes of the constituents.

Next to water it is the most universal solvent. It is especially useful as a solvent of certain resins and alkaloids which are insoluble in water.

To test for alcohol in a liquid add HCl and enough potassium dichromate to give an orange-yellow color. Divide between two test-tubes for comparison. Heat one until the liquid boils. If alcohol is present, the color will change to green and give off odor of aldehyd.

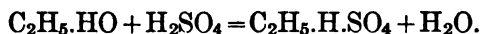
The strength of alcohol is usually determined by its specific gravity. This may be determined by using a hydrometer for liquids lighter than water, or by weighing a few cubic centimetres carefully measured, the weight in grams per cubic centimetre will be its specific gravity (1 cubic centimetre H_2O at standard density = 1 gram).

In the commercial grades, *rectified spirit* has a specific gravity of 0.838 and contains 84% of alcohol; *proof spirit* has a specific gravity of 0.92 and contains only 49% of alcohol. This is the weakest spirit that will answer the old rough proof of firing gunpowder which has been moistened with it.

Ethyl Ether, $(C_2H_5)_2O$.

May be considered as derived from the corresponding alcohol by process of dehydration. Ethyl ether is sometimes called sulphuric ether, from the fact that it is prepared by distilling a mixture of ethyl alcohol with sulphuric acid in the proportion by volume of 2 to 1. The sulphuric acid is left unchanged by the process, the reaction being apparently as follows:

1. Production of hydro-ethyl sulphate $(H.C_2H_5.SO_4)$:



2. Production of ethyl ether heating with more alcohol at $140^\circ C.$:



The ethers as a class are insoluble in water and lighter and more volatile than the corresponding alcohols. They are not as easily acted upon by other bodies chemically as alcohols are.

Ethyl ether is a very mobile, colorless liquid with a characteristic odor; has specific gravity of 0.70 at 15° C.; it boils at 34.9° C.; evaporates rapidly in air at ordinary temperatures, producing great cold and yielding a heavy vapor (specific gravity 2.59) which is very inflammable and in unskilled hands is dangerous. It is very sparingly soluble in water, requiring 10 volumes of H₂O to dissolve 1 volume of ether. 34 volumes of ether are required to dissolve 1 volume of H₂O. But commercial ether contains alcohol, and this latter takes up considerable water. Ether and alcohol may be mixed in any proportion, but the addition of excess of water displaces the ether. Ether is the great solvent for fats.

Acetone, CH₃.CO.CH₃. Dimethyl-ketone.

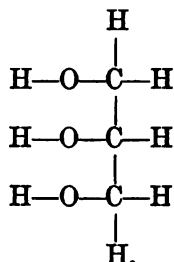
Acetone is the solvent for cellulose that has been nitrated so as to contain a high percentage of nitrogen, say 12.9% or above. At ordinary temperature and pressure cellulose so nitrated is not soluble in the ether-alcohol mixture, but is soluble in acetone. Acetone is found among the products resulting from the distillation of wood. When wood is distilled, the condensed products separate into two layers: the lower is wood-tar, and the upper is a mixture of water, methyl alcohol, acetic acid, and acetone.

Acetone is a colorless liquid with characteristic, pleasant odor; specific gravity 0.81; boils at 56.3° C.

It burns with a bright flame; it evaporates readily, and its vapor is dangerous if mixed with air. It mixes with water, alcohol, and ether in all proportions. Adding KHO to its aqueous solution displaces it and it rises to the surface. It is a good solvent for resins, camphors, fats, guncotton, and nitroglycerine.

Glycerine. Glyceryl Hydroxide. Propenyl Alcohol.
 $C_3H_5(OH)_3$.

Glycerine is a trihydric alcohol, having the structural formula



It may be obtained from all fats and is the sweet principle of them. Fats are sometimes called glycerides.

Glycerine is also formed as a by-product in the alcoholic fermentation of grape-sugar, and is present in small quantities in beer and wine. It is a by-product also in the manufacture of soaps and candles, being separated in the mother-liquor when fats are saponified by lime or superheated steam. The crude glycerine resulting from these processes is purified by distillation. A quantity of crude glycerine is placed in a copper still, and steam at $280^{\circ} C$. is forced through it. The pure glycerine is volatilized, passes over, and is condensed.

Glycerine is a colorless sirupy liquid, its viscosity increasing as the temperature is lowered. Although it is a viscous liquid, it has the property of working its way by capillary action through the smallest openings or fissures. Its specific gravity is 1.269 at $12^{\circ} C$.; it boils at $290^{\circ} C$., but then undergoes partial decomposition; it is slightly volatile at $100^{\circ} C$., but not at ordinary temperatures. Glycerine crystals may be obtained from an aqueous solution kept for some time at $0^{\circ} C$. Pure glycerine solidifies at $-40^{\circ} C$., forming a gummy mass. It ignites at $150^{\circ} C$. in air, burning with a faint blue flame resembling that of alcohol. It absorbs water readily from the air.

It mixes with water and alcohol in all proportions. It is insoluble in ether, but is soluble in ether-alcohol mixtures. It is soluble in carbon disulphide, petroleum, benzine, chloroform. Glycerine is one of the most important solvents, dissolving most substances which are soluble in water, and some others, such as some metallic oxides, which are not.

The best test of identifying glycerine is to mix it with KHSO_4 and heat it strongly, when the unpleasant odor of acrolein (odor of smouldering candles) is noticed.

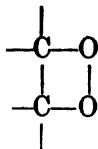
Its importance in explosives results from the fact that it forms nitroglycerine when acted upon by nitric acid.

Cellulose, $\text{C}_6\text{H}_{10}\text{O}_5$ or $n(\text{C}_6\text{H}_{10}\text{O}_5)$.

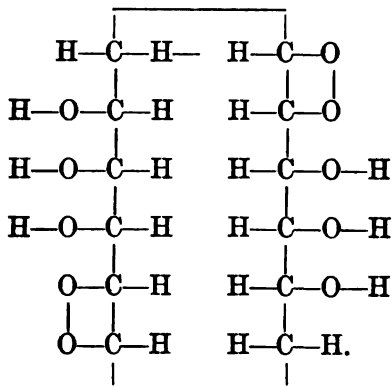
Cellulose is by far the most important substance used in the manufacture of the new explosives. It is the source from which guncotton and most of the smokeless powders are derived.

As already stated, the most recent practice classifies cellulose as a hexhydric alcohol, although its molecule has not the simple structure of the alcohol series.

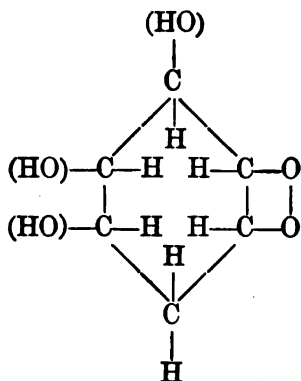
Captain Willoughby Walke, Artillery Corps, on page 205 of his Lectures on Explosives, gives the suggestion of Dr. John W. Mallet, the celebrated chemist of the University of Virginia, that only three atoms of hydrogen are grouped in the hydroxyl radical, the fourth hydrogen atom being united directly to the carbon atom, while the corresponding oxygen atom and the remaining free oxygen atom are linked together with the same carbon atoms after the manner of grouping of oxygen atoms in quinone, thus:



If this be adopted, the cellulose molecule may be written as follows for the double molecule:

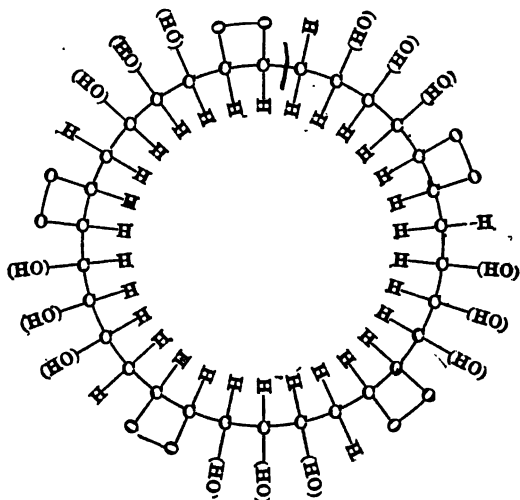


The formula for the single molecule $\text{C}_6\text{H}_{10}\text{O}_5$ may be arranged after the plan of the quinone group, thus:



A cellulose ring may be written composed of any number of groups of this type of arrangement. It should be understood, however, that this arrangement of the cellulose molecule is theoretical and of value only in so far as it agrees with observed chemical facts.

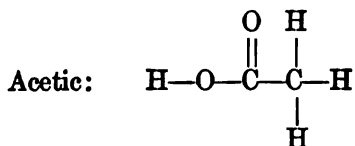
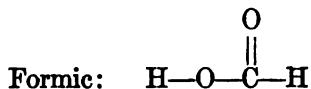
The group $5(\text{C}_6\text{H}_{10}\text{O}_5)$ would be written structurally as follows:

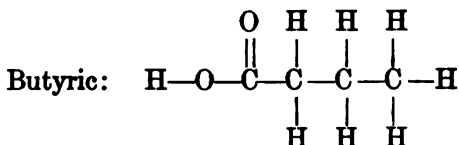
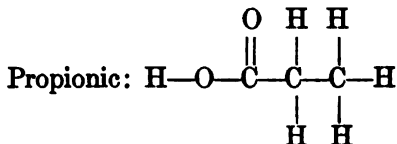


Cellulose is the constituent of the cell-walls of all plants. When the soluble ingredients of all forms of vegetable life are removed, with mineral substances, cellulose remains as a white, opaque, organized structure. White filter-paper, cotton wool, and pure linen fibre are familiar examples of cellulose.

It is infusible; insoluble in all ordinary solvents. It is dissolved by "Schweitzer's Reagent" (a solution of cupric hydroxide in ammonia); it is precipitated from this solution by adding an acid.

Cellulose subjected to heat alone, as in destructive distillation, breaks up into organic volatile compounds, especially into certain organic acids, such as:





Strong sulphuric acid acts on dry cellulose, converting it into a gummy mass which dissolves in the cold in an excess of the acid with very little color.

Unsize paper immersed in a cold mixture of strong sulphuric acid with one-half its volume of water converts the cellulose into a tenacious translucent substance called amyloid. A strong solution of zinc chloride affects cellulose in the same way. This property is made use of in manufacturing vegetable parchment, shipping-tags, cartridge paper, etc.; it increases the strength of paper about five times and makes it water proof.

Cellulose left in a bath of sulphuric acid (specific gravity 1.453) or in hydrochloric acid (specific gravity 1.16) for 12 hours is converted into a brittle mass of hydrocellulose ($\text{C}_{12}\text{H}_{20}\text{O}_{10} \cdot \text{H}_2\text{O}$) which is more easily oxidized than cellulose and is soluble in a hot solution of potassium hydroxide. This is made use of in separating cotton from old fabrics (rags) of cotton and wool mixed; the wool remaining is called shoddy. Dry-rot in wood is supposed to be due to a similar change.

The action of nitric acid on cellulose will be described later, in connection with the manufacture of guncotton and smokeless powders.

III.

GENERAL REMARKS ON EXPLOSIVES.

As a matter of practical military interest, explosives may be divided into three classes, namely:

1. Progressive or propelling explosives. (Low explosives.)
2. Detonating or disruptive explosives. (High explosives.)
3. Detonators or exploders. (Fulminates.)

The first includes all classes of gunpowders used in fire-arms of all kinds; the second, explosives used in shell, torpedoes, and for demolitions of all kinds; the third, those explosives used to originate explosive reactions¹ in the first two classes.

Each of these classes is distinguished by the character of the explosive phenomenon it produces, and it may be said that, corresponding to these respective characteristics, explosive phenomena may be divided into three classes, namely:—

1. Explosions proper: explosions of low order; progressive explosions; combustion.
2. Detonations: explosions of high order.
3. Fulminations: the characteristic type of explosion produced by the fulminates, possessing exceptional brusqueness.

¹ An *explosive reaction* is a chemical reaction usually involving the change of state of a substance from a solid or liquid to a gas, attended with great increase of volume, or the combination chemically of two or more gases with sudden increase of volume.

Explosion Proper. (Explosion of Low Order. Progressive Explosion.)

As the heading implies, this class of explosion is marked by more or less progression; the time element is involved as a controlling factor, the time required to complete the explosive reaction being large compared with that in the other forms of explosion. In this class of explosion the time consumed in the reaction is to some extent under control by varying the physical characteristics of the explosive. The explosion, indeed, is of the nature of an ordinary combustion. The mass is ignited at one point and the reaction proceeds progressively over the exterior surfaces and then perpendicularly to these surfaces until the entire mass is consumed.

The explosion of a charge of black, brown, or smokeless powder is not different in principle from the burning of a piece of coal, wood, or other combustible; there is a *progressive* change of state from particle to particle, from the solid state to the gaseous state, accompanied by the heat due to the chemical change.

The word "combustion" as used above has a definite meaning. It is the combination of the carbon and hydrogen of a combustible with oxygen. The *calorific value* of a combustible is the number of units of heat involved in its combustion.¹ This is independent of the time involved; it is the same whether the change takes place in a fraction of a second or is prolonged through years; a pound of wood will give the same number of units of heat whether it be burned as fine shavings or pass into the gaseous state through slow oxidation in the air. *Calorific intensity* is the maximum possible *temperature* of the products of combustion.² It is determined by the *time*

¹ Unit of heat is the amount of heat required to raise a pound of water from 0° C. to 1° C., or from 32° F. to 33° F.

² It may be defined as the temperature to which the heat generated by the burning of each portion of the fuel can raise its own products of combustion when burned in its own volume without loss of heat due to conduction or radiation.

of combustion. Its numerical value is determined by dividing the total number of units of heat produced by the number of units of heat required to raise the products 1° C. at the temperature of these products.

It may be represented in the form of an equation as follows:

Let H = total number of units of heat produced;

$\left. \begin{array}{l} W, \\ W', \\ W'', \\ \text{etc.,} \end{array} \right\} = \text{weights of products of combustion;}$

$\left. \begin{array}{l} S, \\ S', \\ S'', \\ \text{etc.,} \end{array} \right\} = \text{heat required to raise 1 unit of weight } 1^{\circ} \text{ C. at the} \\ \text{temperature and pressure of the products} = \\ \text{specific heats of products;}$

T = calorific intensity.

Then

$$T = \frac{H}{WS + W'S' + W''S'' + \text{etc.}}$$

The heat of combustion is due chiefly—

1. To H burning to H_2O .
2. To C burning to CO , in limited supply of oxygen.
3. To C burning to CO_2 , in unlimited supply of oxygen.

The calorific value of most substances may be estimated approximately from the molecular composition, by determining the number of atoms of C and H that are free to combine with O. In some combustibles, as in the carbohydrates, part of the O is present in association with H in the molecule in the proportion found in the water molecule (H_2O) and no heat results from these atoms; indeed, on the contrary, heat is absorbed in the physical change of state of this water to vapor. Water held mechanically in the pores or intermolecular spaces of substances must be treated in the same way. It requires 537 units of heat

to convert one pound of water at 100°C. into one pound of steam at 100°C. This is the latent heat of evaporation or condensation. To evaporate 9 pounds of water (containing 1 pound of H) at 100°C. requires $537 \times 9 = 4833$ units of heat. Eight pounds of O combine with 1 pound of H to produce 9 pounds of water-vapor at 100°C. , and, in doing so, produce 29,629 units of heat. This is the calorific value of hydrogen when the products are in the state of vapor. If this water-vapor be condensed to liquid water at 100°C. , the latent heat of condensation must be added to this, and the calorific value of hydrogen when the product is in the form of liquid water at 100°C. is $29,629 + 4833 = 34,462$ units of heat. In the same manner $\frac{1}{2}$ pounds of O combining with 1 pound of C produces 2481 units of heat in burning to CO; $\frac{1}{2}$ pounds of O combining with 1 pound of C produces 8080 units of heat in burning to CO_2 .

If the weights and specific heats of the products of combustion are known, it is possible to compute the maximum possible temperature developed in an explosive reaction.

The specific heats of gases which constitute the chief products of combustion in explosions vary with the temperature and pressure, and their values at high temperatures and pressures are not known accurately.

Temperature and pressure are both dependent on the space in which the reaction takes place. In a restricted space, like the chamber of a gun, both the temperature and pressure rise very high, and as a result of the high temperature the phenomenon of *dissociation* may occur; that is, the elements may separate by a physical process due to the weakening of the molecular bonds by the action of the high heat.¹ The effect of this "dissociation" is to reduce temperature. The motion of the projectile in the gun, enlarging the volume, will reduce pressure and temperature. The result is, at a certain stage of the lowering of both temperature and pressure, chemical combination again takes place and the heat due to this tends

¹ Oxygen and hydrogen at atmospheric pressure separate at 2800°C.

to increase the pressure. The phenomenon of dissociation occurs in the first instants of explosions; the phenomenon of recombination in the later instants.

Heat thus may be the cause of directly resolving a substance into its component parts; if the body is reformed upon the lowering of the temperature, the phenomenon is *dissociation*; if not reformed, it is *decomposition*.

When a body is disintegrated by heat in a confined space, some of the products being gaseous, the disintegration proceeds until the gas or vapor liberated has attained a certain pressure, greater or less according to the temperature. No further disintegration then takes place, nor will the separated elements combine so long as that particular temperature and pressure are maintained. If the temperature be raised, disintegration will be resumed until some higher limiting pressure is produced; if the temperature be lowered, combination will take place until a certain lower pressure is attained; if the temperature remain constant and the pressure be increased, combination will take place; if lowered, disintegration. The amount of dissociation is definite in all cases for the same substance and the same condition of temperature and pressure.

This action is not limited to compound substances, but is believed to take place with the molecules of the elements; that is, the molecules of multi-atom molecules may be dissociated by heat into their separate atoms.

Detonation. (Explosion of High Order.)

The second class of explosion is of a different nature. The explosive reaction is not confined to the surfaces exposed, but appears to progress in all directions throughout the mass, radially, from the point of initial explosion; it appears to pass from the molecules at the initial point to those adjacent, and from these to the next adjacent, and so on, throughout the body, at a very rapid rate. Apparently the atomic bonds of

the initial molecules are disrupted by the molecular energy or blow at the initial point; this breaking up of the initial molecules is transmitted by a wave-like action known as *the explosive wave*, extending throughout the body, the initial disruptive energy being transmitted from molecule to molecule, and these, in succession, giving way, the nascent atoms thereof combining according to the newly existing affinities which yield mostly gaseous substances.

The effect is to transform the explosive in an almost inappreciably brief time from the solid or liquid state to the gaseous state, the gases being greatly increased in volume and pressure by the heat of combination attending the reaction. It has been determined experimentally that the velocity of propagation of the explosive wave throughout a mass of guncotton is from 17,000 to 21,000 feet per second.

The calorific value and calorific intensity of disruptive explosives may be determined as explained for progressive explosives, the combination between oxygen and carbon and hydrogen having the same heat value regardless of the form of explosion.

The phenomena of dissociation and combination may take place in the products of this type of explosion, also, giving rise to a more prolonged explosive blow than in the case of the explosion of fulminates.

Fulmination.

This class of explosion is still more brusque than the last. It is like the last in that the initial molecule is broken up by the crushing effect of the blow due to the exciting cause, and the molecular energy thus applied is transmitted by the disruption of the first molecules to those adjacent, and these to the next, and so on throughout the mass.

The characteristic feature of this form of explosion is the *absence of dissociation*. The gases are evolved in such a simple form that there is little or no dissociation and the new affinities

do not invite chemical combination. The explosive blow is thus not prolonged by these phenomena, and is therefore relatively much sharper than in the last class.

The heat of the first phase of the explosion is also very great, tending in itself to increase the sharpness and energy of the blow on the initial molecules.

A brusque explosive blow such as described is thought to have the effect of breaking up the molecular bonds of explosive molecules, and thereby initiating an explosive wave throughout the mass of the explosive. With progressive powders, it would be effective in initiating the explosion, but there would not, in ordinary cases, be an explosive wave. It is this property of initiating detonation and explosion which gives rise to the use of the detonators or exploders. They are used in caps and primers of all kinds; the abruptness of their explosion, and the consequent sharpness of the blow and the concentration of heat on the point of ignition, constituting their efficiency as originators of explosions of the first two classes.

In all cases, explosions are attended by a sudden and large increase of volume of the substances which constitute the explosive. Generally there is also evolution of heat; always so when due to chemical reaction in the first phase of the explosion, and recombination after dissociation in the later phase.

An explosion due to physical causes alone, as when compressed air is released, causes cold; the firing of the pneumatic gun produces so much cold as to cause the condensation of the water-vapor in the air of the charge as it leaves the muzzle of the gun.

IV.

PROGRESSIVE EXPLOSIVES.

Progressive explosives may be considered under the two headings:

1. Charcoal powders.
2. Nitrocellulose powders.

CHARCOAL POWDERS.

These may be divided into:

1. Black charcoal powder, or black powder.
2. Brown charcoal powder, or brown powder.

Black Powder.

In the manufacture of black powder, fully charred black charcoal is used. The wood is charred at about 130° C.

Charcoal charred at this temperature contains about 76 parts by weight of pure carbon, 4 parts of hydrogen, 19 parts of oxygen, and 1 part of ash.

The ingredients of black powder are, besides pulverized charcoal, pulverized sulphur and pulverized nitre. The proportion in which these ingredients are mixed is about as follows:

75	parts	by	weight	of	nitre;
15	"	"	"	"	charcoal;
10	"	"	"	"	sulphur.

Variations from these proportions occur in different countries, but the differences are insignificant.

The ingredients are purified as a preliminary step. They each are then pulverized by grinding.

The charcoal is ground in a machine resembling a large coffee-mill. It consists essentially of a vertical metal cone, having teeth placed spirally on its surface. This revolves within a vertical cylinder, having teeth projecting inwardly and arranged spirally, inclining in the opposite direction to that of the teeth on the cone. These teeth are susceptible of adjustment, so that the clearance between the two sets may be increased or decreased. By this means the degree of fineness of the ground charcoal is regulated.

The sulphur and nitre are ground in a machine resembling a mortal-mill. It consists of a pair of circular edge-rollers, travelling around a strong, circular cast-iron bed, revolving at the same time on their axes. The rollers are about 4 feet in diameter and weigh about 3000 pounds. They are placed at different distances from the centre of motion, so that each passes over the cast-iron bed on a separate path, one being just inside of the other. The two rollers have a common horizontal shaft about which they turn. At a point on this horizontal shaft, nearer one roller than the other, is a vertical spindle, which is geared below to the driving-train of machinery, so as to give a motion to both rollers about this spindle. The nitre or sulphur is spread evenly over the bed, about 1 to 2 inches thick, and motion given to the rollers. They move over the material, and in a few minutes it is reduced to a fine powder. A scraper follows behind each roller, and is so formed as to throw the material under the next following roller.

After grinding the charcoal, nitre, and sulphur, each is passed through a separate *sifting-reel*. This sifting-reel consists of a frame cylinder covered with wire cloth, 32 meshes to the inch. The ground materials pass through the interior of this reel, which revolves slowly. The fine particles suitable for powders pass through the meshes and fall into a bin. The coarser particles pass through the reel, are received in a barrel at the lower end, and are taken back to the grinding-mill for regrinding.

The sifted materials are weighed out very carefully in 50-pound lots, in the relative proportions given above (75 parts of nitre, 15 parts of charcoal, and 10 parts of sulphur), and placed in bags. The contents of one bag constitute a charge for the *mixing-machine*.

The mixing-machine consists of a copper drum mounted on a horizontal shaft. The drum has a capacity of about 150 lbs. of the mixed materials. It revolves at about 35 revolutions per minute. The shaft of the drum is hollow, and through this passes a second shaft, which carries a series of arms or "flyers" on the interior of the drum. These arms are flat, with forked ends, and just clear the interior surface of the drum. They revolve in the opposite direction to the drum at about 70 revolutions per minute.

Three bags of the ingredients are emptied into the drum, the machine set in motion, and the mixing is completed in five minutes.

The *mixed ingredients* are allowed to fall through a chute into a tub, carefully examined to see that the mixing is regular, placed in bags, and tied very compactly. These bags are laid on their sides to prevent, in so far as possible, the tendency of the ingredients to separate in layers according to their specific gravities; when necessary to handle the bags, it should be done carefully and without jarring or shaking, for the same reason.

The mixed ingredients are next taken to the *incorporating mill*, to be put through the process of *incorporation*. This is the most important process in the manufacture of charcoal powder. Its object is to bring the ingredients into the closest possible contact, so that each particle of the resulting *cake* shall be composed of the three ingredients in proper proportion.

The incorporating mill is of the edge-roller type, like the sulphur and nitre grinding-mills, except more massive; the rollers are about 6.5 feet in diameter, 15 inches wide, and weigh about 4 tons each.

The mixed ingredients from the mixing-machine are spread evenly over the bed of the incorporating mill; it should not be

thicker than 0.5 inch nor less than 0.25 inch: if thicker than 0.5 inch, the incorporation is defective; if less than 0.25 inch thick, there is danger of explosion.

After the charge has been spread over the bed, it is moistened with from 4 to 8 pints of distilled water, depending on the state of the atmosphere. Greatest care must be exercised by the attendant in regulating the water, as the nature of the product depends very much on uniformity in the amount of moisture present.

It requires from 3 to 4 hours to incorporate a charge. The incorporated mass is called *mill-cake*. It should have a uniform blackish-gray color, without any white or yellow specks. A small amount of it flashed on a plate should burn smoothly, at the proper rate, and give little residue.

The incorporated powder, in the form of soft mill-cake, is put into open tubs and placed in small magazines, where it is exposed to the action of the air, so that all workings may either absorb or give off water-vapor and come to about the same percentage of hygroscopic water present; 2 to 3 per cent of water in the mass is necessary to give good results in the subsequent pressing.

In so far as the chemical requirements for combustion are concerned, the powder is now completed. The subsequent operations have for their object the production of certain physical effects, depending upon the use to which the powder is to be put. In order that its rate of burning may be regulated, the *size* and *density* and *form* of the grains must be fixed.

Before being *pressed*, the mill-cake is broken into lumps of uniform size, in a machine called the *breaking-down machine*. This machine consists essentially of two pairs of grooved cylinders arranged one pair above the other. These cylinders are so placed on shafts, and are so geared, that they have motions downward between each pair. The clearance between the cylinders, and the dimensions of the grooves, are adjusted to the nature of the cake, and, for safety purposes, the clearance may be automatically increased by the action of a sliding-bearing

of one of each set of cylinders, which allows this cylinder to move back in case the cake is fed to the rollers too rapidly, or a hard lump happens to pass through. The hopper of the breaking-down machine takes about 700 lbs. of mill-cake. It is open below, resting on a continuous canvas belt with cleats, which, as it moves, feeds the mill-cake to the top set of cylinders. After passing through these, the cake falls between the second set of cylinders and then into suitable box-cars or trucks. It requires about a half-hour to break down a charge of 700 pounds. The product of the breaking-down machine is called *powder-meal*. It is stored again for several days, so as to equalize the moisture, and is then ready for *pressing*.

In order that the powder may be granulated, it is first pressed into solid compact cakes, called the *press-cakes*. These are formed by hydraulic pressure, applied to powder-meal placed between gun-metal plates, in a large, strong, gun-metal box. The press-box is laid on its side, and the upper side removed; the metal separating-plates are inserted; the meal is filled in between the plates, the space between plates being about $\frac{1}{4}$ of an inch: the box is then placed under the head of an hydraulic ram and pressure applied. The plates are free to move under the applied pressure and compress the powder-meal to a hard, compact cake.

Sometimes the press-plates are so made as to form certain regular shapes in the press-cake. The hexagonal and spherohexagonal powders, formerly used in the United States service, were so formed; the upper and lower surfaces of the press-cake were formed into regular hexagonal or spherical shapes, with a thin partition between the forms at the middle of the dividing section.

The press-cake is broken up into *grains* by passing through the granulating-machine. This consists of a series of pairs of gun-metal cylinders, with teeth of suitable size and suitably placed on the surfaces of the cylinders. The press-cake passes between these rollers, and is broken into grains of various sizes. There is a screen under each pair of rollers, to catch the broken press-cake and to conduct it to the next set of rollers; the size

of the mesh of these screens is 8 meshes to the inch. Besides these conducting screens, there are three separating screens extending under all of the cylinders. The upper one has 8 meshes to the inch; the second, 16 meshes; the third is copper-wire cloth. The powder collected on each screen is conducted to a separate tub. The powder collected on the top screen is reworked; that on the second screen is "cannon" powder; that on the third screen is rifle powder; that which passes through the third screen is powder dust. The sizes of the breaking-down teeth, and of the screen-meshes, are altered to suit the special requirements of any particular granulation that may be desired.

The sharp corners of grains are worn off and the dust separated from any grade of grained powder by the *dusting-machine*. This consists of horizontal cylindrical frames, covered with canvas, having 24 meshes to the inch. Several barrels of foul grain are put in the cylinders, and the latter set to revolving at about 40 revolutions per minute. In about half an hour the process is completed, the powder dust having passed through the meshes of the canvas.

In some cases, with small-arm powders, the cylinder is given a slight slope.

At the end of the process, the powder is collected in barrels. Sometimes it is necessary to repeat the dusting once or twice before the powder is sufficiently free of dust.

Some powders are *glazed*. The grains are put into a horizontal, barrel-like receptacle, and revolved for 5 to 6 hours with a small quantity of pulverized graphite. The object of this is, to make the powder less liable to form dust in storage and transportation, and to protect the grains to some extent from the effects of moisture in the air.

The final operation is to remove excess of moisture from the powder by *drying*. The powder is spread out over shallow canvas-bottom frames, arranged in tiers, over a steam radiator, and is subjected to a temperature of 130° F. for 16 to 18 hours. After standing for 2 to 3 hours to allow it to cool, it is run through a dusting-reel and then packed.

Usually black powder is packed in 100-pound packages. The

receptacles are, as a rule, either wooden barrels or metal canisters. If wooden barrels are used, the wood is oak and the hoops are made of some wood, like cedar, not liable to become worm-eaten. Zinc-lined boxes have also been used. These boxes are often arranged to be hermetically sealed, or are provided with gasket covers, to protect the powder in storage from the moisture of the air.

Black gunpowder should be of even granulation, of good hardness and density, free from dust. A small quantity poured on the back of the hand should leave little or no trace of dust; when flashed in 10-grain samples on a copper plate, there should be no bead or excessive residue. It should give the proper initial velocity in the arm for which it was intended, and absorb little water from the air.

Brown Powder.

The foregoing description applies in its essential features to the manufacture of all mixtures of nitre, charcoal, and sulphur. In *brown powder*, the charcoal is made from rye-straw and is under-charred. The proportions of the ingredients vary some from those given for black powder, the proportions for brown powder being, approximately:

Nitre.....	80 parts
Charcoal.....	16 “
Sulphur.....	3 “
Moisture.....	1 part

100

This mixture is slower burning than black powder. Its introduction marked the last phase of a long line of investigation, begun in the early sixties in the United States by the late General T. J. Rodman, Ordnance Department, U. S. Army. Some reference may well be made here to that series of experiments which, initiated by Rodman, were taken up and extended by many others, both in the United States and in Europe, especially as the principles established thereby still survive and apply to the new powders.

Rodman sought to increase the powers and endurance of large guns by controlling the combustion of powders used in them. He conceived the idea that there were certain definite relations among the elements, size, form, and density, that would give a *best powder* for a given gun, that is, a powder which would give the highest velocity for a given pressure; or, stated in other words, a *special powder* could be determined for each piece of ordnance, and the idea came to be known as the *principle of special powders*. In carrying out this idea, he experimented with powder having much larger grains than had been used prior to his time, and with powders of varying density and forms, including those subsequently known as "mammoth," "pebble," lenticular, perforated prismatic, and perforated cylindrical cake-powders.

The Civil War put a stop to Rodman's experiments, and, after the war, although he desired to continue them, he was, for some reason difficult to appreciate, ordered to a post of duty where it was impossible to give any attention to the matter.

Knowledge of his work had, however, become known abroad, and the line of investigation was taken up there, resulting, after a time, in the adoption of the perforated prism as the standard form of grain for large guns.

The fundamental idea involved in this development may be said to be, to so control the combustion of a charge of powder in a given gun that there shall be a certain uniformly progressive evolution of gas, so that the projectile will be started from rest under a minimum pressure, with the quantity of gas evolved in consecutive instants of time, gradually increasing until the projectile reaches a certain point in the bore of the gun. The pressure in the gun increases to a maximum soon after the projectile is started, and then falls regularly: the velocity increases to a maximum at a point just beyond the muzzle.

The first step was to gain slow combustion through increasing the density and enlarging the size of the grain; the result of this was evidenced in the old "mammoth" powder that was used in the 15-inch smooth-bore Rodman guns.

The next was, while holding to the above principles, to control the rate of evolution of gas in burning a grain of powder *by perforating it*, and to have thereby a certain portion (from the interior outward) of the grain burn on *increasing surfaces*, giving for *this portion* increasing quantities of gas in succeeding intervals of time.

This same effect was later obtained in another way by the so-called *Fossano Powder*, made in Italy. The powder-grain was in itself a conglomerate of smaller grains bound together by a suitable powder matrix, the whole being compacted into large grains by pressure. As the large grain burned, it was broken up, exposing the surfaces of the smaller grains, and in this way offering successively increasing surfaces for ignition and burning, and, consequently, increasing quantities of gas.

The next was, to establish uniformity in time of burning of each grain by moulding the grains, as in the hexagonal and sphero-hexagonal powders, and, in connection with the pressure applied in forming these moulded powders, to produce a higher density of grain on the surface than in the interior of each grain, illustrating the principle of varying density of grain.

The perforated prism gave, however, the best results, and the right hexagonal prism came in time to be the standard form of grain for large guns the world over. Variation existed in the number of perforations, some prisms having but one perforation, others seven, one opposite each angle and one in the centre. The last-named is thought to be the arrangement generally adopted. That portion of a prismatic grain between the perforations is called *the web* of the grain; its thickness is the determining factor in the time of combustion.

In determining the "special powder" required for a given gun, the density and granulation (number of grains to the pound) of hexagonal and sphero-hexagonal are the data to be fixed by computation or experiment; if prismatic powder is to be used, the dimension of the prism and the number and size of the perforations must be determined.

As the ability of the powder-manufacturers to make slow-

burning powders developed, the maximum pressures in the rear portion of the bores of guns fell, but the pressures in front of the trunnions was increased. At the same time, the gun-makers were able to increase the strength of the built-up gun, so as to make it possible for the gun to bear slightly higher pressure: The improvement in gun-making also made it possible to *increase the lengths of bores*; this, in turn, made it possible to burn more powder in the guns and thereby increase velocity. To receive these larger charges, and also to further control the powder-pressure over the charge, enlarged powder *chambers* were introduced. By properly adjusting the relations the volume of the powder chamber, the weight of charge and of the length of the bore, the pressure corresponding to a given velocity could be kept within the limit of the gun's elastic strength.

Prismatic charcoal powder is made from ordinary granulated powder. Usually the larger size grain is taken as the base. This is reworked, moistened with about 10 per cent of water, and formed into the prisms by passing it through the "spindle-press." This press consists essentially of two sets of powerful stamps operating reciprocally through openings in a heavy mould-plate. The mould-plate has a series of hexagonal *moulds* in it, and is placed so as to be horizontal in the press.

The bottoms of these moulds are formed by the ends of the lower series of *stamps*: these have each a number of needles, usually seven, projecting upward through perforations in the stamps; the upper series of stamps has also similar perforations. In forming the grains, the upper stamps are raised, the lower ones are lowered to their lowest point, forming the bottoms of the moulds. The powder-base is placed in a hopper, the bottom of which has a sliding *charging-plate*, which contains a series of *measures* corresponding to the moulds of the mould-plate. The *charging-plate*, with its measures filled with powder-base, slides over the mould-plate until the measures are directly over the moulds into which the powder-base drops. The *charging-plate* then at once slides back into the hopper, where the measures

are automatically refilled. The press is then put in operation. The upper stamps descend into the moulds, the needles passing up into their perforations and forming the perforation of the prisms. By the reciprocating action of the press, when the upper stamps have reached their lowest point and begin to ascend, the lower stamps follow them up until the ends of the lower stamps are flush with the top of the mould-plate and upper ends of the perforating needles; when this position is reached, the lower stamps stop, the upper ones continue upward, leaving the prismatic grains free to be pushed off by the edge of the charging-plate.

The following data pertain to some of the "special" black powders of the United States old-type ordnance:

Manufacturer's Letter.	Form of Grain.	Density.	Granulation. No. per lb.	Gun Used In.	Weight of Charge, lbs.	Muzzle Velocity, f. s.	Maximum Pressure, lbs. per sq. inch.
E. F. P.	Hexagonal.	1.785	67	10-in. and 11-in. rifles. Old M. L. Experimental 15-in. smooth-bore.			
E. V.	Hexagonal..	1.75	72	8-in. M. L. C.R.	35	1400	35,000
E. V. M.	Hexagonal..			15-in. S. B.	130	1686	25,000
I. B.	Spherohexagonal..	1.728	123	4.5-in. M. L. siege.	8	1567	28,000
I. K.	Irregular. ...	1.725	2200	3-in. M. L. 3-in. 2 B. L. field.	3	1527	26,500

The gaseous products of explosion of brown powder undergo dissociation in the first instants of combustion in the bore of the gun, and recombination takes place as the projectile moves along the bore. The first tends to lower the initial pressure in the powder chamber, and the latter to increase the pressure along the bore. The two combined tend to reduce the maximum pressure, and to raise the minimum pressure and to distribute the stresses due to explosion more uniformly and with less rapid change along the bore. The more gradual applica-

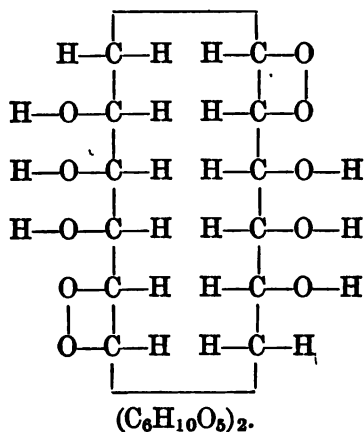
tion of the force and the lower maximum pressure tends to increase the endurance of the gun.

NITROCELLULOSE POWDERS.

Nitrocellulose may be considered as the base of all forms of smokeless powders.

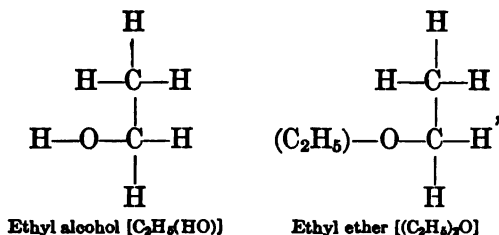
The nitrocellulose molecule contains within itself the elements carbon, hydrogen, and oxygen, so that, when conditions favorable to a disruption of existing molecular bonds and to a recombination of these elements are produced, the reactions of combustion take place, producing the gaseous oxides of carbon and water-vapor. In the case of charcoal powders, these elements were brought by *mechanical* process into such intimate relations that each particle of black or brown powder should contain the elements necessary for combustion. The two classes of explosives have, therefore, a fundamental difference in this respect. In nitrocellulose, the elements to produce combination are present in the molecule in accordance with the law of fixed proportions, in great purity and in closer relations than is possible with a mechanical mixture, like charcoal powder.

It will be remembered that the structural formula of cellulose was written (p. 82) to show its analogy to the alcohols, thus:

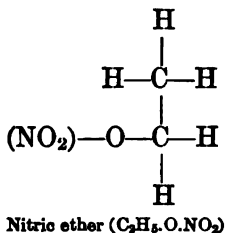


It will be recalled, also, that ethers may be considered to be formed from the alcohols by substituting a suitable hydrocarbon radical for the hydrogen of the hydroxyl radical of alcohol (p. 81).

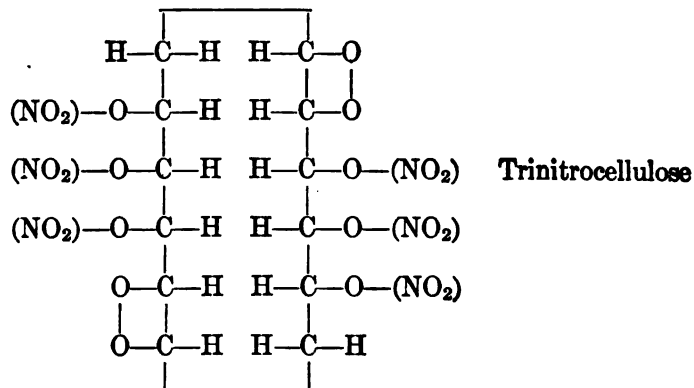
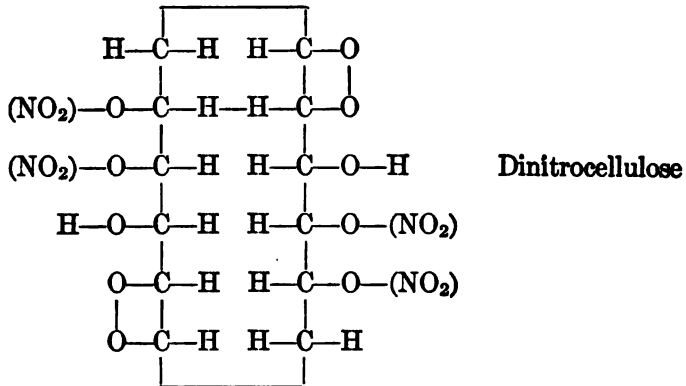
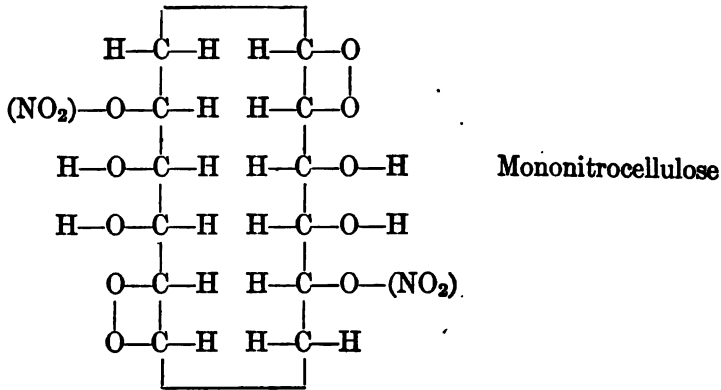
Thus, ethyl ether is derived from ethyl alcohol by substituting the ethyl radical for the hydrogen of the hydroxyl of the alcohol:



In the same way nitric ether may be produced from alcohol by the action of nitric acid on alcohol, the radical nitryl, NO_2 , displacing the hydroxyl hydrogen atom and giving:



In like manner the hydrogen of the hydroxyl radicals of the cellulose molecule may be displaced by NO_2 by the action of nitric acid, giving substances which in molecular structure resemble nitric ethers. There are three hydroxyl groups in the cellulose molecule that are susceptible of this substitution; there may, therefore, be three separate displacements, as follows, using the double grouping:



On account of this and other chemical analogies nitrocellulose is generally classed as a compound nitric ether of the trihydric alcohol, cellulose.

The nitryl radicals which are transferred when cellulose is acted on by nitric acid introduce weak molecular bonds, which give way under the action of heat and permit the elements to combine with great energy, according to their relative affinities for each other, and it is this feature particularly, which constitutes nitrocellulose an explosive. The result of the breaking-up of the trinitrocellulose molecule in explosion may be represented by the following reaction:



The Nitration of Cellulose.

For military explosives, the cellulose used for nitration is, as a rule, the waste from cotton-spinning factories, cotton-cloth factories, or other forms of pure cotton fibre.

Within the past few years much attention has been given to the subject of nitration of cellulose by several eminent investigators and scientists, including Vieille, Bruley, Lunge, Will, and others.¹

In 1878 Dr. J. M. Eder arrived at the conclusion, as a result of a series of experiments, that there were as many as six degrees of nitration of cellulose, three of which he was able to produce and isolate, namely, the *hexa-*, *penta-*, and *di-*; two, the *tetra-* and *tri-*, he obtained in admixture with others; the *mono-* he was unable to prepare.

Eder assumed the double type of molecule, corresponding to C_{12} , and wrote the formulas as follows:

¹ "Nitration of Cotton," by M. Bruley. "Researches upon the Nitration of Cotton," by M. Vieille. "Investigations as to the Stability of Nitrocellulose," by Dr. W. Will. G. Lunge's experiments in nitrating cellulose.

Mono-nitrocellulose.	$C_{12}H_{19}O_9(NO_3)$
Di- "	$C_{12}H_{18}O_8(NO_3)_2$
Tri- "	$C_{12}H_{17}O_7(NO_3)_3$
Tetra- "	$C_{12}H_{16}O_6(NO_3)_4$
Penta- "	$C_{12}H_{15}O_5(NO_3)_5$
Hexa- "	$C_{12}H_{14}O_4(NO_3)_6$

Vieille, as a result of extended research made in 1883, arrived at the conclusion that, in order to account for the amount of NO_2 given by the products of his experiments, the formula $C_6H_{10}O_5$ must be quadrupled, and the molecular formula of cellulose written $C_{24}H_{40}O_{20}$; giving rise to eight varieties of nitrocellulose, as follows:

Cellulose tetra-nitrate.	$C_{24}H_{36}O_{20}(NO_2)_4$
" penta- "	$C_{24}H_{35}O_{20}(NO_2)_5$
" hexa- "	$C_{24}H_{34}O_{20}(NO_2)_6$
" hepta- "	$C_{24}H_{33}O_{20}(NO_2)_7$
" octo- "	$C_{24}H_{32}O_{20}(NO_2)_8$
" ennea- "	$C_{24}H_{31}O_{20}(NO_2)_9$
" deca- "	$C_{24}H_{30}O_{20}(NO_2)_{10}$
" endeca- "	$C_{24}H_{29}O_{20}(NO_2)_{11}$

Of these the *deca-* and *endeca-* varieties were found to be insoluble in ether-alcohol; the *ennea-* and *octo-* were soluble and capable of being colloided; the lower nitrations gave friable products insoluble in ether-alcohol.

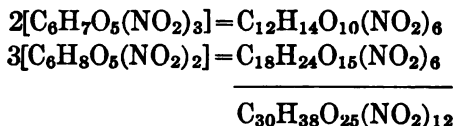
In Vieille's researches the present military smokeless powder may be said to have had its origin. Soon after his deductions were announced, the manufacture of smokeless powder in France was begun. The French powder was kept a secret for some time. The success of the French inaugurated activity throughout Europe, and, before long, the nitrocellulose base came to be the essential ingredient of all smokeless powders.

In Russia the development of a smokeless powder was intrusted to the celebrated chemist, Professor D. Mendeléef. His investigations resulted in the claim that he had been able

to produce a definite nitrocellulose having the formula $C_{30}H_{38}O_{25}(NO_2)_{12}$, which he called "pyrocollodion," which colloided perfectly in ether-alcohol, and in combustion gave the maximum volume gas possible from the elements represented in the molecule, since the content of oxygen, as given in the formula, is just sufficient to burn all of the C to CO, after burning the H to H_2O ; the explosive reaction being as follows:



Mendeléef's claim that his pyrocollodion is a definite compound is disputed. It is claimed by others that the substance is, rather, a mixture of nitrates of different degrees of nitration, such, for example, as the following:



Pyrocollodion, according to Mendeléef, results from the following reaction:



Perhaps the most complete series of experiments made in connection with the nitration of cellulose are those made by the French Government chemist, M. Bruley, published in the *Memorial des Poudres et Salpêtres*, vol. viii, 1895-96, in a paper entitled "Sur la Fabrication des Cotons Nitres," an English translation of which is to be found in Bernadou's "Smokeless Powder, Nitrocellulose, and Theory of the Cellulose Molecule."

M. Bruley points out that of recent years the various grades of nitrocellulose have given rise to many varied uses, such as photographic films, celluloid, mercerized cotton, in the mechanical arts; and guncotton and smokeless powder in military explosives. Each of these requires a special variety of nitrocellulose, and it becomes important, if possible, to fix the conditions which regulate the nature of the product.

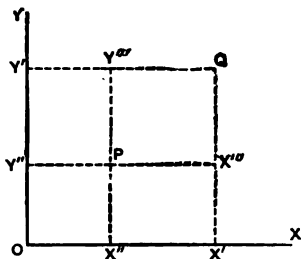
For many years military guncotton had been manufactured from the standard mixture of acids, three parts of sulphuric acid by weight (65.5° Baumé) and one part by weight of nitric acid (48° Baumé). But, as a result, chiefly of Vieille's investigations, his classification of the nitrocelluloses and the manufacture of smokeless powders based on his deductions, it became desirable to determine some practical rules and guides for the manufacture of the new nitrocelluloses of lower nitration.

In the ordinary manufacture of nitrocellulose, the product is apt to contain a mixture of the three classes of nitrocelluloses, guncottons (endeca- and deca-nitrates), collodions (ennea-, octo-, and hepta-nitrates), and friable cottons (penta- and tetra-nitrates). The first of these is insoluble in ether-alcohol, the second is soluble in that mixture, the third not soluble.

The experiments of M. Bruley had for their object, therefore, the determination of some practical method of obtaining a certain desired product in the nitration of cellulose.

His experiments may be well explained by reference to the accompanying figure.

For the purpose of graphically representing the conditions of the experiments let O represent the origin of a set of axes, OX and OY . Let OX represent the axis of the proportion by weight of water used in the mixture, and OY the axis of the proportion by weight of nitric acid used. Let $OX' = OY'$ represent the fixed quantity of sulphuric acid used. Let OX'' represent a certain quantity of water used in a particular experiment, and OY'' represent a certain quantity of nitric acid used in the same experiment. Express OX'' as a percentage of OX' and OY'' as a percentage of OY' ; that is, if OX' and $OY' = 100\%$ weight (the fixed weight of the sulphuric acid), $\frac{OX''}{OX'}$, carried out to hundredths in decimal form, will represent the percentage quantity by weight of water used in terms



of the fixed quantity of sulphuric acid used, and, similarly, $\frac{OY''}{OY'}$ will represent the percentage quantity by weight of nitric acid used in terms of the fixed quantity of sulphuric acid. The line $X''Y'''$ represents the locus of all products, corresponding to the ratio $\frac{OX''}{OX'}$ between water and sulphuric acid.

The line $Y''X'''$ similarly represents the locus of all nitric-acid mixtures, corresponding to the ratio $\frac{OY''}{OY'}$ between nitric acid and sulphuric acid. The point P corresponds to a definite mixture of OX'' parts of water, OY'' parts of nitric acid, and $OX' = OY'$ parts of sulphuric acid. The area $OY'QX'$ includes within it all possible combinations of mixtures of water and nitric acid with sulphuric acid, when the quantities of water and nitric acid do not, either of them, exceed the quantity of sulphuric acid used.

M. Bruley assumed twenty-five points uniformly distributed throughout this area, prepared the mixtures to correspond thereto, immersed the cellulose in these mixtures, and steeped them for 6, 12, and 24 hours, thus producing three series of nitrations. He subsequently determined, by chemical analysis and physical experiment, the following data:

1. The nitrogen content, expressed in c.c. of NO_2 .
2. The solubility in ether-alcohol.
3. The viscosity in ether-alcohol.

The temperature of the immersions was 12° to 13° C.

The water normally present in both nitric and sulphuric acid was determined carefully, and considered as a part of the water ingredient of the acid mixtures. These determinations were 5 to 6 per cent in the sulphuric acid, and 10 to 15 per cent in the nitric acid.

The fixed weight of sulphuric acid taken was 1.2 kilos.

A separate mixture was made for each of the twenty-five points, corresponding to a range of nitric acid of 10 to 60 per cent; and of water, 10 to 45 per cent. The inferior

limit for nitric acid being fixed by the time required for nitration, and the superior limit by that cost of the acid beyond which it would not pay to go in manufacturing nitrocellulose for the trade; the lower limit of water was fixed by the quantity of water always present in the strongest acid, the higher limit by the limit of colloidable nitrocellulose.

When the quantity of nitric acid fell below 15 per cent, the time required to nitrate completely was so prolonged that it would not be practicable, commercially, to use so low a percentage.

The samples consisted of 4 grams of bleached spun-cotton waste, and were immersed in 400 grams of mixed acids.

The table on page 118 gives the results of the experiments.

Bruley divided the products into: (1) guncotton, (2) colloids, and (3) friable cottons.

In general terms it may be said that the guncottons resulted from mixtures within the following ranges of percentages, by weight of nitric acid and water, the weight of sulphuric acid being 100 per cent:

For nitric acid, 55 per cent;	water, 12 to 24 per cent.
“ “ “ 15 “ “ “	8 “ 16 “ “

In the same way the limits of mixtures for the most perfect colloids having, say, a solubility above 90 per cent, were:

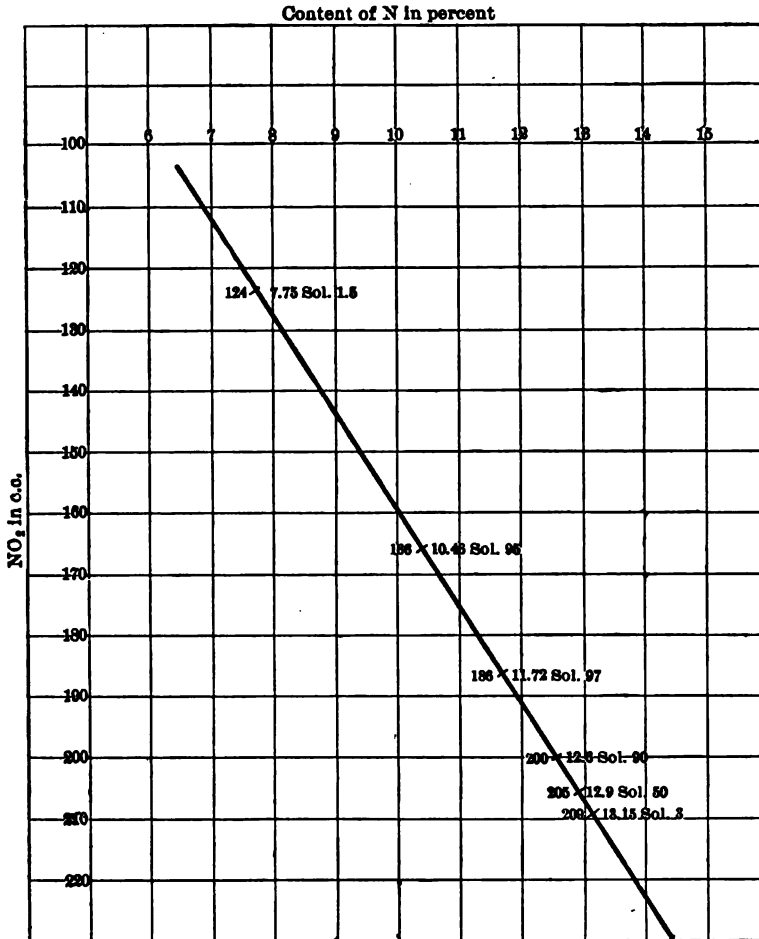
For nitric acid, 55 per cent;	water, 27 to 35 per cent.
“ “ “ 15 “ “ “	18 “ 25 “ “

A fairly high degree of solubility extended beyond these water percentages to about 40 per cent of water for 55 per cent of nitric acid, and about 27 per cent of water for 15 per cent of nitric acid.

Beyond these latter water limits the products were friable cottons.

The guncottons correspond to nitrocellulose, having a nitrogen content above about 12.9 per cent; the higher colloids, a nitrogen content less than about 12.9 per cent and more than

about 12 per cent; the inferior colloids, a nitrogen content of from just below 12 per cent to just above 10 per cent.



For a fixed per cent of nitric acid in a series of mixtures in which the per cent of water only varies, the nitrogen content changes slowly in passing beyond the guncotton zone as the water percentage increases, while, at the same time, the solubility changes very rapidly. A nitrogen content of about 12.5 per cent is soon reached, having a solubility of about 95 per

cent, and after this has been attained considerable variation may be made in the quantity of water with little change in either the nitrogen contents or in the solubility. When the increase of water for this same quantity of nitric acid causes the nitrogen content to fall to about 10.5 per cent, the solubility drops below 90. Beyond this an increase of water causes a gradual decrease in both nitrogen content and solubility to take place until the lowest recorded limit is reached; that is to say, a limit of nitrogen content of about 7.75 per cent and a solubility of about 1.5.

While the relative proportion of the ingredients of the acid mixture is the chief factor influencing the result of nitration other causes have an effect, such as (1) duration of steeping, (2) temperature of dipping and steeping, (3) subsequent steps in purification.

Cotton-wadding nitrates more readily than spun-cotton waste. Generally speaking, the more perfectly the fibres are separated and the waste freed from tangles and knots the quicker and better the nitration.

In order to obtain the same degree of nitration, the steeping should be prolonged in proportion as HNO_3 is reduced in the acid mixture. The influence of duration on the NO_2 content and solubility appears in the following table:

Duration of Steeping.	Inferior Colloid.		Superior Colloid.		Guncotton.	
	I.		II.		III.	
	NO_2 Content, c.c.	Solubility, per cent.	NO_2 c.c.	Solubility.	NO_2 c.c.	Solubility.
1 hr.	165.8	91.7	186.8	94.9	206.4	10.9
2 hrs.	166.8	95.5	189.	95.0	209.4	8.3
4 "	167.8	93.0	191.8	96.2	209.2	6.8
6 "	167.8	94.8	198.	94.1	210.2	6.7
8 "	166.8	95.4	191.8	96.7	210.2	5.6
12 "	210.8	7.4
24 "	166.8	98.1	194.	96.6	210.6	10.6

From which it is observed that with the colloids from 2 to 6 hours are required, and with guncotton, 8 to 10 hours. If

the reaction be continued beyond 6 to 8 hours, the solubility for the same nitrogen content is materially increased.

Increase of temperature, during dipping and steeping, up to 26° C., increases both the solubility and NO₂ content of colloids, and has a tendency to the same for guncottons.

When, therefore, it is desired to produce a definite nitrocellulose it is first necessary to fix the composition of the acid mixture, following the principles set forth above, and testing the nitrogen content by the usual nitrometer method.

While the degree of nitration may be regulated by the foregoing principles, the *stability* of the product depends chiefly on the process of purification. It is found that any nitrocellulose after nitration contains certain nitro-by-products which are more or less unstable, and these are liable to spontaneous decomposition in storage; some of these nitro-products may disintegrate under comparatively low heat and often cause the condemnation of nitrocellulose which, except for their presence, is thoroughly trustworthy. Dr. W. Will, of the German Central Station for Scientific-Technical Investigation, New Babelsberg, near Berlin, has investigated this phase of the problem, and arrived at the conclusion that these nitro-by-products are produced in the nitration of cellulose, besides the nitrocellulose proper, and the nature of these by-products is such that they are not wholly soluble in cold water, and, when cold water alone is used in the purification, they are not carried off. Boiling and subsequent washing in cold water removes them, due, perhaps, to the fact that the boiling modifies the chemical nature of some of these products, rendering them soluble in cold water and, when the latter is applied after boiling, the objectionable products are removed.

Dr. Will claims that when boiling and cold washing are properly conducted, practically all of such unstable by-products are removed, and the resulting nitrocellulose proper, whatever its degree of nitration, is a safe compound and may be stored for years under normal temperatures, without change. Nitrocellulose so prepared is said by him to be in its "limit state,"

and such nitrocellulose, if subjected to a higher heat, say 135° C., as in the German heat-test, will evolve equal volumes of N in equal times; this Time-Nitrogen relation, when plotted, approximates closely to a right line for the limit state.

Nomenclature of Nitrocelluloses.

There are various products resulting from the nitration of cellulose to different degrees and under different conditions. These may be enumerated as follows, following the nomenclature given by Bernadou:

Nitrocellulose. A general term applied to products resulting from the action of nitric acid on cellulose, in which the organic cellular structure of the original cotton fibre has not been destroyed.

*Nitrocellulose of high nitration.*¹ Those in which the content of nitrogen is large, say 12.9% or greater.

*Nitrocellulose of mean nitration.*¹ Those in which the content of nitrogen is mean, say less than 12.9% and greater than about 11%.

*Nitrocellulose of low nitration.*¹ Those in which the content of nitrogen is less than about 11%.

Insoluble nitrocelluloses. Those insoluble in ether-alcohol mixture² at ordinary temperature and pressure.

Soluble nitrocelluloses. Those soluble in ether-alcohol mixture at ordinary temperature and pressure.

Hydrocellulose. The product obtained by acting on cellulose with the fumes of HCl, or by immersing cellulose in HCl, H₂SO₄, or very dilute HNO₃. It is a white, pulverulent mass which, examined under the microscope, shows that the cellular tissue of the original cotton fibre has been modified.

Nitrohydrocellulose. The product resulting by acting on hydrocellulose with HNO₃ (strong), the product still retaining the modified cellular form of the hydrocellulose.

Nitrohydrocellulose of high nitration. Contains relatively a high per cent of N.

Nitrohydrocellulose of mean nitration. Contains relatively a mean per cent of N.

Nitrohydrocellulose of low nitration. Contains relatively a low per cent of N.

Insoluble nitrohydrocellulose. Those insoluble in ether-alcohol at ordinary temperature and pressure.

¹ See Vieille's Classification of Nitrocelluloses (table), p. 123.

² In the proportion of 2 parts by volume of ether to 1 part by volume of alcohol.

Soluble nitrohydrocellulose. Those soluble in ether-alcohol at ordinary temperature and pressure.

Guncotton. Those nitrocelluloses of high nitration used for disruptive purposes in war. They consist, as a rule, of a mixture of insoluble nitrocellulose with a small quantity of soluble nitrocellulose and a very small quantity of unnitrated cellulose.

Pyrocellulose. A soluble nitrocellulose of so called definite percentage of N(12.4), corresponding to the molecular formula, $C_{30}H_{28}(NO_2)_{12}O_{26}$, claimed to have been produced by Mendeléef; it possesses just sufficient content of O to burn all of the C to CO, the H to H_2O .

Colloid, or collodion nitrocellulose. Nitrocellulose that may be colloided in ether-alcohol.

VIEILLE'S CLASSIFICATION OF NITROCELLULOSES.

Molecular Formula.	Designation.	Theoretical c.c. of NO_2 .	Experimental c.c. of NO_2 .	Theoretical per cent of N.	Remarks.
$C_{24}H_{20}O_{22}(NO_2)_4$	Tetra-nitrocellulose	108	109	6.76	Only slightly attacked by acetic ether and ether-alcohol. } Friable cottons.
$C_{24}H_{20}O_{20}(NO_2)_6$	Penta-nitrocellulose	128	132	8.02	
$C_{24}H_{20}O_{20}(NO_2)_6$	Hexa-nitrocellulose	146	143	9.15	
$C_{24}H_{20}O_{20}(NO_2)_7$	Hepta-nitrocellulose	162	164	10.18	Becomes gelatinous in acetic ether and ether-alcohol. } Inferior colloid.
$C_{24}H_{20}O_{20}(NO_2)_8$	Octo-nitrocellulose	178	182	11.11	Soluble in ether-alcohol. } Superior colloid.
$C_{24}H_{20}O_{20}(NO_2)_9$	Ennea-nitrocellulose	190	192	11.96	Highly soluble in ether-alcohol. } Gun-cotton.
$C_{24}H_{20}O_{20}(NO_2)_{10}$	Deca-nitrocellulose	203	205	12.75	
$C_{24}H_{20}O_{20}(NO_2)_{11}$	Endeca-nitrocellulose	214	215	13.47	Insoluble in ether-alcohol. Soluble in acetone. }

According to Guttman Vieille's formulas are not beyond question. Guttman himself claims to have made guncotton on a large scale, containing 13.65 per cent of nitrogen, which, according to Vieille, would be impossible.

Colloidization.

After cellulose has been dipped in nitric acid ("nitrated") and "purified" of the free acid and nitro-by-products by boiling and washing in water, it possesses a property it did not have before, namely, it is soluble in certain liquids in which it was not soluble as cellulose. The two most important of these liquids are *acetone* and a mixture of *ether* and *alcohol*, in the proportion by volume of 2 to 1.

If an excess of the liquid be used a true solution is formed, and if the liquid be evaporated off, the nitrocellulose will remain as a horn-like compact mass, called "colloid," in which all evidences of cellular structure has disappeared. If the quantity of solvent be reduced sufficiently, the solid nitrocellulose will soften and take the form of a paste-like mass, one of the states passed through from the true solution to the compact, horn-like solid in evaporating the solvent.

This process of dissolving nitrocellulose and producing the colloid form of it is called colloidization.

In connection with nitro-explosives there are two important series of colloids: one, the acetone series; the other, the ether-alcohol series.

Acetone dissolves the nitrocelluloses of highest nitration, and gives colloids which are characterized by brittleness. Under pressure or shock they break up. This fact renders such colloids dangerous when used alone for powder; the shocks due to handling and the pressure in the bore of a gun would cause grains to be disintegrated, the rate of combustion to be enormously increased, and excessive pressures.

The ether-alcohol colloids, on the other hand, are tough and elastic. It is from this class of colloids that most smokeless powders now in use are made.

The several physical states of the two series of colloids, as a result of evaporation from the solution, may be described as follows:

Acetone series: Liquid, slime, plastic mass, brittle colloid.

Ether-alcohol series: Liquid, jelly, elastic mass, tough colloid.

Manufacture of Smokeless Powder.

While there are minor differences in the manufacture of smokeless powder as conducted at the different factories, the essential steps are the same, and are performed in practically the same manner. The following description of the commercial method of manufacture gives these steps in sufficient detail.

1. CLEANING.

- (a) *Washing-house.* The *base*, in the form of cotton-waste or cotton rags, is brought to the washing-house in large bales. These are broken open and the waste put into the
- (b) *The Washer.* *washer.* This consists of a large iron cylinder mounted on a horizontal axis, with pipes running through the centre, which carry steam for heating the charge. The cylinder is filled with a solution of caustic soda and the cotton-waste is added to this. The washer revolves very slowly. Its motion keeps
- (c) *First Washing.* the mass constantly agitated, and accomplishes the removal of oil and grease. A temperature of 120° to 130° F. is maintained during the washing, which lasts about 4 hours.
- (d) *Centrifugal Wringer.* From the washing-house the cotton is taken to a centrifugal wringer, and wrung as dry as possible.
- (e) *Second Washing.* It is then returned to the washer and washed a second time in clear, pure water.
- (f) *Second Wringing.* It is then wrung out a second time in the centrifugal wringer.
- (g) *The Picker.* After the second wringing it is taken to the *picker.* The cleaned cotton-waste, or rags, is placed on the apron of the machine, which conducts it between two horizontal toothed cylinders which revolve in opposite directions, pulling in between them the cotton, tearing apart the knots and tangled lumps of waste, or the cotton rags, into shredded strips, about 1 inch to 1½ inches long, and about ¼ inch wide. After passing through the picker it is collected in boxes and taken to the *drying-house.*

2. DRYING.

Drying-house.

This house has large wooden bins with perforated bottoms. Hot air circulates under the bottoms, and is forced up through the bins and through the *cleaned, dried, and picked* cotton placed therein. The temperature of the air is from 90° to 105° F. The cotton is turned over by hand from time to time. It is kept in the bins about 8 hours. It then contains about 0.5% of water. As soon as the cotton is thus dried it is placed in air-tight cans. This is necessary, as it absorbs from 1½% to 2% of water by mere exposure to the air. It is then taken to the *nitrating-house*.

3. NITRATING.

(a) *Nitrating-house.*

The cotton, as now prepared, is nitrated in earthen pots containing the acid mixture, or by placing it in a centrifugal machine, so arranged as to allow the acid mixture to be admitted and the spent acids to be withdrawn through suitable pipes with stop-cocks. In case the nitration takes place in a centrifugal machine it is conducted as follows: One can of dried cotton, containing about 16 pounds, is placed at one time in the machine with about 900 pounds of mixed acids, consisting of 3 parts sulphuric acid and 1 part nitric acid, both very strong, 98% and 95% respectively. The mixed acids are drawn from a large tank, called the mixed-acid tank. The spent acids, after "revivifying" by additions of "fortifying" acids of concentrated strength, are let into the mixed-acid tank.

(b) *The Acids.*(c) *Nitration.*

The charge is kept in the centrifugal machine about 30 minutes. In becoming nitrated the cotton increases in weight about one-half; the 16 pounds of cellulose giving about 24 pounds of nitrocellulose. The degree of nitration is about 12.6% of N. During the 30 minutes the charge is turned over and over by iron hooks.

(d) *Drawing off
Spent Acid.*

After 30 minutes the drain-cocks of the machine are opened, the machine is started, and the spent acids are forced out by centrifugal action.

4. PURIFICATION.

The remainder of the process has for its object getting rid of the free acids remaining in the nitrated cotton and of the nitro-by-products.

(a) *Drowning.*

The nitrated cotton is taken at once from the nitrating machine, and immersed or drowned in a large quantity of pure cold water. It is kept immersed in this water for 8 hours, two changes of water being made.

(b) *First Washing.*

From the drowning-tanks the cotton is taken to another centrifugal machine. The machine is started as soon as the charge is in it, and while it is revolving cold water is played on it from a hose. After about ten minutes the washing is discontinued, and the machine then revolved at its highest capacity and the cotton wrung as dry as possible.

About 1000 pounds are allowed to accumulate from the foregoing operations, and this constitutes a factory "lot."¹ This lot receives a definite number which attaches to it throughout its existence. In connection with this number all subsequent purification operations, stability- and ballistic-tests are recorded.

(c) *Purifying-tanks.*

These are large wooden tanks, having steam-pipes arranged over the bottom. Steam circulates through these pipes and keeps the cotton and water at the desired temperature. Pure water is put in the tanks and one lot added. The lot is kept in the purifying-tank for two days, the temperature being maintained at 80° C., except that the water is renewed three times during this period, and at each renewal the temperature is raised to 100° C. for two hours. The mass is kept agitated by revolving arms set at different angles.

(d) *First Purification.*

In some factories the purification consists of alternate two-hour washings at 80° and 100° C., with renewal of water each time to include five renewals.

(e) *Second Washing.*

From the purifying-tanks the nitrated cotton is taken to a centrifugal machine, where it is washed

¹ The size of the "lot" of different factories varies.

with pure cold water from a hose for a few minutes. It then goes to the *pulper*.

(f) *Pulper*.

This is the ordinary pulping-machine used in paper-mills. It consists of an oval-shaped vat or tank, with a horizontal shaft across its narrowest dimension. On one end of this shaft is a drum, which has on its outer surface a series of parallel knife-edges. Directly below the drum is a concentric surface, with a second series of knife-edges. The clearance between these edges can be regulated. Pure water circulates slowly through the vat, running in at one point and overflowing at another. About 1000 pounds of cotton from the purifying-tank is placed at one time in the pulper. The contents of the vat are submitted to an acid color-test from time to time, and sufficient sodium carbonate is added to neutralize any free acid that may be liberated as the pulping proceeds. The drum revolving pulls the cotton down and forces it between the two series of knife-edges, cutting it finer and finer until the whole mass is a smooth, even, fine pulp, about the consistency of corn meal; this requires about six hours. From the pulper the cotton goes to the *poacher*.

(g) *Poacher*.

This is a vat similar to the pulper in form, but it has no knife-edges. The horizontal shaft across its narrow part carries only wooden paddles. The object of the machine is simply to continue the washing, with a view to removing all free acid or alkali. The contents are tested for both acid and alkali as the poaching proceeds. The operation is continued until the lot is shown to be free from acid and alkali. A chemical stability-test is now made. Further treatment depends on its result. Another form of poacher consists of large, deep, cylindrical vats, with a propeller-shaped wheel on a vertical axis near its bottom. Steam-pipes may be placed over the bottom, and the mass subjected to the action of boiling water and rewashing with cold water, as in the purifying-vats. The propeller keeps the mass circulating. The process should continue for three days, having twelve changes of water and two hours' boiling with each change.

(h) *Second Purification*.

- (i) *Third and Final Washing.* From the poacher, as just described, the cotton is dumped into a large volume of pure cold water, which is contained in a large trough. Through the trough circulates an endless belt of coarse cotton cloth, which passes between two rollers at some distance outside of the trough. As the belt moves through the mass of suspended cotton a certain quantity adheres to it, and the belt carries this up through the rollers, which squeeze out the surplus water, and a scraper detaches the squeezed cotton from the belt and it falls into receptacles placed to receive it on the other side of the rollers. It is now in the form of small thin flakes. It contains about 4% of water. This is submitted to careful laboratory tests.

5. COLLOIDIZATION.

- (a) *Dehydrating.* This product is taken to the *dehydrating-press*. The water is extracted by means of alcohol; the latter displacing the water. The alcohol thus mixed with the cotton is sufficient to accomplish its colloidization when mixed with ether in the next operation. In extracting the water, 15 pounds of nitrocotton is placed in the cylinder of the dehydrating-press, and submitted to a pressure of 3000 pounds per square inch, which forms it into a cylindrical "cheese." A large quantity of water is pressed out by this pressure, but some still remains. A quantity of alcohol is let into the press cylinder. Air is admitted over the alcohol, and a pressure of 100 pounds per square inch put on. This forces the alcohol through the mass of the cheese, and the liquid flows out through a pipe below; first water comes, then a mixture of water and alcohol, and, finally, alcohol of full strength. A pressure of 3000 lbs. per square inch is again put on the cheese, and this forces out surplus alcohol. Enough remains for colloidizing. The cheese now weighs about 17 lbs., 15 lbs. of cotton and 2 lbs. of alcohol.
- (b) *Colloidizing.* From the dehydrating-presses the product is taken to the colloidizing-machine. This consists of an

ordinary bread-dough kneading-machine, as used in large bakeries. Three cheeses from the dehydrating-press are broken up and put into the kneader with about one-half the weight of ether. The kneader is started, and the mixing continues until all of the ether is absorbed, which, as a rule, requires about two hours. When the colloid is finished, the charge from the mixing-machine is pressed into a cake by hydraulic pressure. This cake is a cylinder about $9'' \times 14''$. The product should now be a smooth, compact colloid, with a clear amber or light brown color. Some few white spots seen in the colloid cake are air-bubbles. To get rid of these air-bubbles and to blend better the colloid, the cake is put through the *macaroni press*.

6. GRANULATION.

(a) *Macaroni Press.*

This is an hydraulic press, having small holes in the bottom of its cylinder. The colloid is forced by the pressure through these small holes, and falls in a receptacle below in macaroni-like strings. These are collected and put into the final press, and pressed into the final *powder-cake*.

(b) *Die-press.*

The powder-cake is put through the *die-press*, from which it emerges in the form of a continuous cord- or rope-like cylinder, of the diameter of the powder-grain being made, and with the requisite perforations. This result is accomplished by having the end of the press a cone, and fitted into the apex of the cone is a die, with needles of proper size for the perforations. The press is horizontal. The head forces the colloid to fill the cone and surround the needles. Continued pressure forces the colloid out through the die; it is received on rollers, carried thereon to the end of a long table, at which point a revolving disk-cutter cuts the rope into grains of proper lengths. The die can be changed so that one press may turn out many sizes of grain.

7. DRYING.

(a) *Solvent Recovery.*

The grains from the powder-press are collected in suitable cases and taken to the *solvent-recovery*.

house. At this house the grains are placed in certain receptacles, and hot air forced up through them. This hot air carries off the greater part of the solvent, the grains shrinking and shrivelling in the process. The air, laden with the vapors of alcohol and ether, passes to an elaborate refrigerating-apparatus, in which the two vapors are separately condensed and collected. The process takes about 8 hours. About 60% of the solvent should be recovered, but this degree of efficiency is rarely attained.

(b) *Dry-house.* The powder is then taken to the *dry-house*, where it is kept from two to four months in a drying temperature of 100° to 105° F.

In the manufacture of smokeless powder for the United States, the alcohol used is supplied by the Government, 1.2 pounds being allowed for each pound of powder accepted. Ether is supplied by the manufacturer.

All powder is doubly blended before being formed in acceptance lots.

The delivery of a lot of powder dates from the completion of the blending and boxing it, at which time the powder inspector of the Government selects samples for chemical analysis and for ballistic test. Its acceptance depends on the passage of these tests.

Powder is shipped in zinc-lined boxes containing, approximately, 100 pounds. Each box is marked with the number of the lot, maker's initials, year, gun intended for, muzzle-velocity, pressure, and granulation.

General Remarks on Smokeless Powders.

Powder, such as that just described, is a pure cellulose or colloid powder. Sometimes nitroglycerine or certain metallic nitrates are added to the colloid in the mixing, with a view to giving a better ballistic effect. These substances when added are to be considered as distributed throughout the mass of the colloid: the nitroglycerine like water in a sponge, the metallic nitrates like particles of sand, or earth, in ice made from muddy

water. They are not *essentials*; they are added to modify the character of the explosion in the bore of a gun.

The ballistic efficiency of a powder may be represented by the ratio:

$$\frac{\text{Velocity given to projectile in f. s.}}{\text{Pressure in tons per sq. in. in bore}}$$

It is desirable that this ratio should have a maximum value.

The strength of guns now in use limits the denominator to about 16 to 18.

With this limitation muzzle-velocity for a given projectile is dependent on the rate of burning of the powder, its quantity, and the length of bore.

Under existing conditions a muzzle-velocity of about 2300 f. s. may be had in guns having bores about 35 calibers long, about 2600 f. s. in guns having bores about 40 calibers long, and 2800 to 3000 f. s. in guns having bores about 50 calibers long.

It has been universally thought desirable, heretofore, to so design a nitro-powder that the carbon would all burn to carbon dioxide. Lately this has been questioned by Mendeléef, who advances the claim that the best results with progressive explosives are to be had when the carbon is burned to CO instead of CO₂, for the reason that a given weight of carbon will give double volume of CO compared with CO₂ at same pressure and temperature, and this will be more efficient in a gun than the increase of volume due to the increased temperature in burning to CO₂. Furthermore, the higher temperature of the products of explosion when C is burned to CO₂ is so destructive to the metal of the bore of guns by erosion as to make such explosives less desirable.

For example, military guncotton has insufficient oxygen to burn all of its C to CO₂, and nitroglycerine has an excess of oxygen. By mixing these two substances in proper proportions, the excess of oxygen in the explosion of the latter supplies the deficiency of oxygen in the explosion of the former, and the products of explosion of the mixture are CO₂, H₂O, and N.

The English smokeless powder, cordite, is an illustration of such a combination; it is composed of

Guncotton (acetone colloided)	37 parts
Nitroglycerine	58 “
Vaselin.	5 “
	<hr/>
	100

It gives high muzzle-velocities with low pressures, but the temperature of its explosion is very high comparatively, and has caused thereby such rapid erosion of the bores of English guns as to cause it to be discarded in favor of a powder with less nitroglycerine, about 38 per cent.

The celebrated French BN powder had barium and potassium nitrate.

The explosion of such powders containing an oxygen carrier disseminated throughout the mass of the colloided nitrocellulose, appears to be more prolonged and increasing in its effect than that of the pure colloid powders.

Based on the foregoing considerations nitrocellulose powders may be classified as follows:

I. PURE COLLOIDS.

- (a) *Acetone colloids.* Composed of nitrocellulose of high nitration colloided in acetone. Such colloids are brittle, and apt to disintegrate under pressure in the bores of gun, giving excessive pressures. They are dangerous.
- (b) *Ether-alcohol colloids.* Composed of nitrocellulose of mean nitration colloided in ether-alcohol. Such colloids are tough and elastic, and do not break up under pressure in the bores of guns.

II. COMPOSITE COLLOIDS.

- (a) Acetone colloid for matrix with nitroglycerine.
- (b) Acetone colloid for matrix with metallic nitrate.
- (c) Ether-alcohol colloid for matrix with nitroglycerine.
- (d) Ether-alcohol colloid for matrix with metallic nitrate.
- (e) Acetone colloid for matrix with organic nitrate.
- (f) Ether-alcohol colloid for matrix with organic nitrate.

Some examples of these types of powders are given in the following table:

PURE COLLOIDS.

ACETONE.		ETHER-ALCOHOL.	
<i>Maxim-Schupphaus.</i>		<i>Mendeléej.</i>	
Guncotton.....	80.	Pyrocellulose, $C_{20}H_{18}(NO_2)_{11}O_{25}$, con-	
Nitrocellulose (sol.).....	19.5	tains 12.4 per cent of nitrogen.	
Urea.....	0.5		
	<hr/>		
	100.0	<i>Powder for U. S. Army (Cannon).</i>	
<i>Poudre B (Vieille's Powder).</i>		Nitrocellulose containing not less	
Guncotton.....	68.21	than 12.65 per cent of nitrogen	
Nitrocellulose (sol.).....	29.79	± 0.5 per cent.	
Paraffin.....	2.00		
	<hr/>	<i>Powder for U. S. Navy (Cannon).</i>	
	100.00	Nitrocellulose containing from 12.4	
		to 12.8 per cent of nitrogen.	
<i>Rifleite.</i>			
Guncotton.....	75.		
Nitrocellulose (sol.).....	22.48		
Nitrobenzene.....	2.52		
	<hr/>		
	100.00		
<i>Indurite.</i>			
Guncotton.....	40.		
Nitrobenzene.....	60.		
	<hr/>		
	100.		
<i>Swiss Normal Powder.</i>			
Guncotton.....	96.21		
Nitrocellulose (sol.).....	1.80		
Resin.....	1.99		
	<hr/>		
	100.00		

COMPOSITE COLLOIDS.

METALLIC NITRATES AND NITRO-
DERIVATIVES OF THE AROMATIC
SERIES.

NITROGLYCERINE.

Plastomenite.

Nitrocellulose (N = 12.33%)	67.18
Barium nitrate.	9.76
Tolnen dinitrate.	22.06

Ballistite.

Guncotton.	50
Nitroglycerine.	49
Diphenylamine.	1

Poudre BN.

Guncotton.	38.67
Nitrocellulose.	33.23
Barium nitrate.	18.74
Potassium nitrate.	4.54
Sodium carbonate.	3.65
Solvents, etc.	1.29

Cordite.

Guncotton.	37
Nitroglycerine.	58
Vaselin.	5

Schulze.

Guncotton.	32.66
Nitrocellulose.	27.71
Cellulose.	1.63
Barium nitrate.	27.62
Potassium nitrate.	2.47
Paraffin.	4.20
Solvents, etc.	1.48

Maxim-Schupphaus.

Guncotton.	80
Nitrocellulose.	10
Nitroglycerine.	9
Urea.	1

E. C. Powder.

Guncotton.	28.35
Nitrocellulose.	27.95
Cellulose.	3.15
Potassium and barium ni- trates.	37.80
Resins, etc.	2.75

U. S. Naval (Small Arms).

Nitrocellulose.	
Barium nitrate.	
Potassium nitrate.	

U. S. Army (Small Arms, W. A.).

Guncotton.	
Nitrocellulose.	
Nitroglycerine.	
Metallic nitrates.	
Deterrent.	

V.

DETONATING EXPLOSIVES.

(a) Guncotton.

As already explained guncotton is nitrocellulose of high nitration, containing above 12.9 per cent of nitrogen. Its manufacture has been described in connection with the manufacture of smokeless powder. The degree of nitration is regulated by the relative quantities of water, sulphuric acid, and nitric acid used in the nitrating bath, the time and temperature of the steeping. The purification of guncotton for disruptive military uses is accomplished in the same manner as described for nitrocellulose used in the manufacture of smokeless powder.

In manufacturing guncotton for military purposes, purified pulp, produced as explained under the head of manufacture of smokeless powder is taken from the poacher to a *stuff-chest* by suction. This consists of a large vat with air-tight top. Through the centre of the vat passes a vertical shaft, on which are mounted a number of feathered paddles. After the purified pulp has been sucked up into the stuff-chest it is kept agitated by these paddles, so that the pulp will be kept evenly distributed in suspension throughout the liquid.

From the stuff-chest the pulp is drawn into the *moulding-press*. This is an hydraulic press made of bronze and containing moulds. The pulp is run into these moulds, and the pressure applied for about four minutes. The mould-press blocks are taken to the *final press*, placed in the moulds of the final

press, and the pressure applied, increasing from a minimum of 6000 to a maximum of 7000 pounds per square inch, through an interval of about three minutes; the highest pressure is maintained for one minute.

The blocks as they come from the final press contain about 15 per cent of water. While in the press they are stamped with the name of the factory, the lot and year. Before being issued for storage or service they should be soaked in pure water until they contain about 35 per cent of water.

In order to get dry guncotton for primers a block of wet guncotton is split up into one-half inch sections; these are strung on a copper or brass wire or tube separating the sections from each other, and exposed to a drying atmosphere out of direct rays of the sun. The sections should be weighed from time to time, and the drying should continue until the weights are constant.

While, theoretically, 183.3 pounds of guncotton (trinitro-cellulose) or 176 pounds of endeca-nitrocellulose (Vieille's) should be obtained from 100 pounds of cellulose, in practice the yield is about 105 pounds of guncotton to 100 pounds of unnitrated cotton; this makes about 230 blocks.

After nitrating and before pulping, guncotton retains the complete cotton structure; even under the microscope no difference is to be detected between nitrated and unnitrated cotton. The only outward evidences of the change is the rough feeling it has, the crackling sound when rubbed between the fingers, and its electrical properties, sticking to the fingers if rubbed between them. Rubbed in the dark, dry guncotton is to some extent phosphorescent.

It may easily be distinguished from unnitrated cotton by treating with solution of iodine in potassium iodide, and subsequently moistening with dilute sulphuric acid. Unnitrated cotton, when so treated, gives a blue color; nitrated cotton, a yellow.

Dry guncotton varies in color from white to light yellow. The yellow is often an indication of sodium carbonate. Some-

times, there is a brownish or reddish shade; this is due, as a rule, to iron, from the washing-water.

When pure, it is without color, odor, or taste, and free from either alkaline or acid reaction.

The density of unpulped dry cotton is about 0.1; after pulping, about 0.8; and in the block form after compression, about 1.2. The absolute specific gravity of guncotton is 1.5.

It is insoluble in both hot and cold water and in alcohol, ether, and ether-alcohol, at ordinary temperatures.

It is soluble in acetone, acetic ether, and the nitro-derivatives of the aromatic hydrocarbons.

It is insoluble in nitroglycerine; but both guncotton and nitroglycerine dissolve in acetone, and a combined colloid may be obtained by dissolving them in this solvent and then evaporating the common solvent. Soluble nitrocellulose is partly soluble in nitroglycerine, and explosive gelatine is based on this property.

Guncotton is completely decomposed by boiling in a solution of sodium sulphide, while unnitrated cotton is not; this principle is used in analyzing guncotton.

Caustic potash solution, with alcohol added, decomposes guncotton almost instantly.

For disruptive purposes, guncotton is used to fill the cavities of shell, to charge torpedoes, and for demolitions of all kinds. For these purposes, it is pressed by hydraulic pressure while in the wet state, in the form of purified pulp, into suitable disks, blocks, or special forms. It is not colloided.

Its value as a disruptive agent rests upon its great force, and its safety in handling, storage, and manufacture.

While many disastrous explosions have occurred with it in the past, none have of late years; and the fact that it is kept in storage in the wet state in which it is non-explosive, except with a powerful detonator or a small piece of dry guncotton, makes it less likely to accidental or spontaneous explosion than any other explosive now used.

If properly purified, guncotton may be kept for years,

even in the dry state, without the slightest deterioration. If not purified completely, some of the nitro-by-products may decompose, and these initiate a progressive decomposition of a mass of guncotton. If, however, the gases generated in such decomposition are free to pass off, the mass will quietly disintegrate. The first evidences of decomposition are acid fumes. These may be recognized by their pungent odor, or, if a piece of moist, blue litmus paper be *confined* with a mass of guncotton thought to be in the state of incipient decomposition, it will soon be reddened. As its decomposition progresses, the fumes become more copious and may be seen as the reddish-brown gas, NO_2 (nitric peroxide). At the same time, the mass begins to show soft, pasty, yellow spots, which extend and coalesce until the whole mass is soft and pasty; and, in connection with the escape of gas, the mass shrinks in volume. As the process proceeds, other gases than NO_2 pass off. The residue is an amorphous, porous, sugar-like substance, almost entirely soluble in water. As long as the gases escape and the heat developed by the reactions is carried off with them, there is no danger of explosion; but if the gases cannot escape, the pressure increases, the heat is retained, the reaction is accelerated, the temperature rises, and ultimately an explosion may result from these causes.

In the case of a mass of decomposing guncotton, it should be spread out, exposed to the air, out of the sun, and wetted with water.

While nitrocellulose is one of the safest explosives known and, when carefully purified, is not liable to decomposition, still it should be kept in mind that it is an explosive, and due care in handling and storing it should be observed.

Some authorities claim that strong light will act slowly to originate the decomposition of nitrocellulose; but Abel, who made searching investigation of this matter, says that "guncotton produced from properly purified cotton may be exposed to *diffused* daylight, either in the open air or in closed vessels, for very long periods, without undergoing any

change. The preservation under these conditions has been perfect after three and one-half years." But long-continued exposure of dry guncotton to the direct rays of strong sunlight produces a very gradual change. If moist guncotton be exposed to sunlight, it is affected to some greater extent than dry guncotton, but the change is very small even after several months' exposure to sunlight in a glass bottle.

It has been found that guncotton, exposed to the sunlight without confinement, has had its stability, as determined by the heat-test, improved. This would seem to suggest that the action of sunlight decomposes the unstable nitro-by-products, and the escape of these into the air slowly leaves the nitrocellulose proper in a purer and more stable state. Indeed, the evolution of acid fumes from a nitrocellulose exposed to strong, *diffused* light would be evidence of incomplete purification.

Instructions for blending or drying smokeless powders require that the operation be performed out of the direct rays of the sun.

Heat of sufficient degree, of course, disintegrates the nitrocellulose molecule; but nitrocellulose of either high or low nitration, that has been properly purified, will stand a temperature approaching 130° F. without change.¹

Water or a damp atmosphere serves to protect nitrocellulose from the disintegrating effect of heat (not light). A guncotton stored in water or in damp magazines is able to withstand,

¹ "In general, it may be said that no nitro-compound will stand heating to temperatures above 160° F. for any prolonged period. At 194° F., even the best and purest product is sure to decompose within a few hours, and even pure guncotton cannot be exposed to a temperature above 122° F., without impairing its capability of subsequently standing the heat-test. It is true, decomposition may not take place at this temperature, and that the product may be kept indefinitely without decomposition under favorable conditions; but whenever it is again subjected to the heat-test at 160° F., it will at once give a distinct reaction. In general, it would appear that only the most perfect products will stand a temperature of 113° to 122° F. for some months without impairing their capability of standing the heat-test."—GUTTMANN.

without change, temperatures as high as 200° F. for long periods. This property renders guncotton a desirable explosive in hot, damp climates. Water not only protects the nitrocellulose proper from the disintegrating action of heat, but also the nitroby-products present in incompletely purified nitrocellulose.

To be non-explosive, it is only necessary that the guncotton be damp; nitrocellulose, with only the water left in it after coming from the centrifugal wringer, is not to be exploded by fire or ordinary shock.

Guncotton made for disruptive purposes contains, as a rule, a small amount of carbonate of sodium; this, disseminated through the mass of the cotton, tends to neutralize any free acid that may be formed in storage. It would not be desirable to have it in finished smokeless powder, as it would increase the solid residue in guns and cause some smoke.

Guttmann is opposed to the use of sodium carbonate in guncotton even to neutralize free acid due to incomplete purification or incipient decomposition. If the guncotton is properly purified, there is no reason why there should be free acid, or why decomposition should take place; and if decomposition should begin, the action of the carbonate would only neutralize the first gases given off, it would not arrest the process: indeed, alkalies have a tendency to decompose nitrocellulose at temperatures above 86° F. It is not desirable to check incipient decomposition by sodium carbonate; on the contrary, if incipient decomposition takes place, it is desirable that the gases given off should pass off and serve themselves to give evidence of the condition existing. "At ordinary temperatures—that is, those occurring under normal circumstances of storage and carriage—decomposition of guncotton, so far as present experience goes, is out of question."

Cold has no effect on dry guncotton. The compressed cakes and disks are caused to flake off on the surfaces if wet and exposed to freezing and thawing, and the freezing also causes the mass of the cake or disk to open out and be less compact.

Variations of temperature between 105° F. and 32° F. have no effect on either the physical or chemical conditions of guncotton.

Guncotton, even when dry, is not liable to explode by blow or friction, unless very closely confined and compressed. For example, in order to explode by a blow a piece of guncotton, it is necessary to take a small piece, wrap it tightly in tin-foil, place on an anvil, tap it two or three times lightly to compress it, then strike it a heavy blow. Shells filled with disks of dry compressed guncotton have been fired from guns into masonry at fifty yards from the gun without explosion.

Flame, or metal heated to red or white heat, will ignite guncotton. Its rate of burning is affected by the degree of confinement and physical state of the mass: if woven into wicks or compact cloth, the rate is much reduced; if compressed while in the pulped state into compact blocks, its rate is also reduced. Burning guncotton may be extinguished by water; but if a mass of considerable size be burning, it may be quenched on the exterior and continue to burn in the interior. Wet guncotton in any form cannot be ignited by flame. A wet disk of guncotton thrown into a fire will first dry out on the outer surface and burn there, and continue this progressively until the whole disk is consumed. As much as a ton of wet guncotton has been consumed in this way without the slightest evidence of explosion.

The igniting-point for nitrocellulose is about 186° C.

The specific heat of the gases composing the products of explosion may be taken approximately at 0.28.

The experiments of Roux and Sarrou indicate 1056.3 centigrade units of heat given off by the explosion of guncotton. This indicates a temperature of 3700° C. Nobel and Abel fixed the temperature, as a result of their experiments, at 4400° C. Sarrou and Vieille found that water was dissociated at the temperature of the explosion, all of the carbon burning to CO₂. Berthelot estimates that guncotton of density 1.1, exploded in

its own volume, will give a pressure of 160 tons per square inch. The rate of propagation of the explosive wave of guncotton in rigid tubes has been found to be 5000 to 6000 metres per second.

Experiments of Professor C. E. Munroe, at the naval guncotton factory at Newport, R. I., have shown that thoroughly dry guncotton can be detonated by three grains of mercury fulminate; air-dry guncotton, by five grains, if the fulminate be confined in copper tubes and the tubes are *in close contact with the cotton*. The Navy primers, however, have 35 grains of mercury fulminate in order to have a liberal certainty factor.

A disk of guncotton detonated on an iron plate reproduces on the surface of the plate the reliefs and depressions on the surface of the disk; a depression on the surface of the disk will be reproduced as a depression on the surface of the plate. The explanation of this is to be found in the erosive effect of the rushing gas at those points where there is no contact; it is the same effect as is to be noted near the bands of projectiles in the bores of guns: the enormous velocities of the gaseous molecules impinging on the metal at these points, in connection with the weakening of bonds of cohesion and affinity by the high heat, is thought to be sufficient to account for the phenomenon.

The violence of explosion is greater in proportion as the confinement is greater; the maximum being when confined rigidly in its own volume, and, in accordance with this principle, tamping increases the violence of an explosion. Even the amount of air-pressure will have its effect on the character of an explosion; the same explosive and detonator would give a more mild explosion on a mountain-top than at the seashore.

Wet guncotton gives a more brusque explosion than dry guncotton; and Professor Munroe explains this by supposing that the water in its pores, being nearly incompressible and highly elastic, increases the rate of propagation of the explosive wave or disturbance and diminishes thus the time of explosion.

The energy of the explosive wave may be sufficient to initiate

explosion in a mass placed at a certain distance from an exploding mass. This is called explosion by influence. Two theories are advanced to account for the phenomenon: One, that the explosion is due to certain *synchronous* relations of the motions of the molecules of gas and the molecules of guncotton,—that a wave of certain amplitude and length passing over the guncotton causes “sympathetic” motion to be taken up by the latter, and this in turn accomplishes the disruption of the guncotton molecule; just as a string of a musical instrument may be set to vibrating by sounding near it the note which gives the wave of sound that correspond to the string, or as certain glass beads under strain may be shattered by musical notes of certain pitch. The other considers that in all cases the explosion is initiated by the *energy of the impact of the molecules in motion*,—that there is a definite product of molecular mass into molecular velocity, which, if it be delivered against a molecule of guncotton, will disrupt the molecule, and the disruption of one molecule will disrupt all adjacent molecules, and so on. As temperature varies directly with molecular velocities, an explosive molecule, for a given pressure, requires a given temperature to disrupt it.

While both theories have advocates, the latter is thought to be more generally accepted at the present time. Some authorities claim that in all cases heat initiates explosions.

Explosion by influence may be illustrated by placing guncotton disks side by side at varying distances apart ($\frac{1}{4}$ ", $\frac{1}{2}$ ", $\frac{3}{4}$ ", 1") and noting the effect.

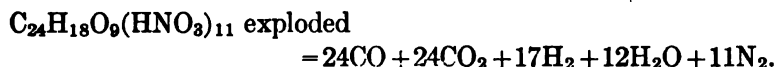
Berthelot fixes the heat of combustion of guncotton at 12 calories for each nitryl radical, and, accepting the products of explosion as determined by Sarrou and Vieille, gives the total heat of combustion at 633 calories per molecular weight proportion.

Sarrou and Vieille conducted a series of experiments in which guncotton was exploded in a closed vessel. They found the volume of gases reduced to 0° C. and 760 mm. pressure, to vary with the density of the charge, both as to proportion of each kind and total volume. Some of their results are given in the following table:

Density of charge.....	0.01	0.023	0.2
Volume of gases (reduced) per material.....	658.5	670.8	682.4
Composition of gases per 100 volumes:			
CO.....	49.3	43.3	37.6
CO ₂	21.7	24.6	27.7
H.....	12.7	17.2	18.4
N.....	16.3	15.9	15.7
CH ₄	0.0	trace	0.6
			and N.

From this it appears that the proportion of CO and N decrease, and CO₂ and H increase, as the density of charging increases; also, that for the higher charging a little CH₄ appears.¹

From these results Berthelot writes out the following reaction for the explosion of guncotton exploded in closed vessels, under the ordinary conditions of charging for disruptive purposes, as in torpedoes:

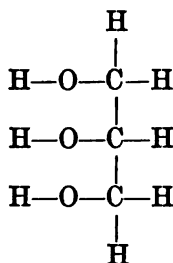


When guncotton is burned in the open air there is some nitric oxide in the products of combustion, amounting to about 24 per cent of the total volumes of the product.

(b) Nitroglycerine.

Nitroglycerine is a nitric ether of propenyl alcohol (commonly termed glycerine).

Propenyl alcohol is trihydric and may be written structurally:



or, in ordinary symbols, C₃H₅(HO)₃.

¹ This CH₄ may, perhaps, account for the flare-backs from cannon in using smokeless powder.

The nitric ether is formed by replacing the H of the HO radicals by NO_2 , and theoretically there may be three ethers, corresponding to one, two or three replacements of H, forming:

Mononitroglycerine, $\text{C}_3\text{H}_5(\text{HO})_2\text{ONO}_2$,

Dinitroglycerine,¹ $\text{C}_3\text{H}_5(\text{HO})\text{O}_2(\text{NO}_2)_2$,

Trinitroglycerine, $\text{C}_3\text{H}_5(\text{NO}_2)_3$.

Only the last is of interest.

The process of manufacture of nitroglycerine follows in a general way the operations performed in the manufacture of guncotton, and consist essentially of:

1. Nitrating the glycerine; and,
2. Purifying the product of free acid and other nitro-compounds.

In nitrating, it is not possible to place a large amount of glycerine in the acid, for the reason that the action would be too energetic and the temperature would rise too high. Therefore the process is so modified as to bring small amounts of pure glycerine (free from lime, iron, aluminum, chlorides, fatty acids, glucose, or other adulterants, having a specific gravity of 1.26) in succession into the presence of the mixed acids.

Sulphuric acid is used in the acid bath for the same reason as in making nitrocellulose.

The acids must be of the highest possible concentration, in the proportion of 1 part by weight of nitric acid (93% to 95%) to 2 parts by weight of sulphuric acid (96%).

According to the chemical formula, 227 parts of nitroglycerine should be obtained from 92 parts of glycerine and 189 parts of nitric acid; in practice it is necessary to take a much higher proportion of acid. As a rule, 1 part of glycerine is taken to 8 parts of nitric acid and about 14 parts of sulphuric acid.

In order to keep down the heat developed by the reaction, the glycerine must be kept between 68° and 77° F. This is regulated by the amount of glycerine injected into the mixed acids. The heat is caused by the water combining with the sulphuric

¹It is understood that quite recently dinitroglycerine has been used with very promising results in a new explosive.

acid. A rise in temperature may explode the nitroglycerine or cause a loss of product, converting it into oxalic acid and other products; these are difficult to remove, and make the nitroglycerine unstable if not removed. This excessive heating is called "firing." If the temperature rises above 86° F. and cannot be controlled by stopping admission of glycerine, compressed air is forced through pipes into the mixture, and the acid bath cooled by the expansion of this air and the agitation it causes. If the temperature still continues to rise, the whole charge is run out into safety tanks. These safety-tanks are large leaden chambers or vats, situated at some distance from the nitrating apparatus into which, in case of firing, decomposing mixtures may be run directly at any stage of the manufacture and "drowned" in a large mass of cold water, which is kept agitated and cooled by compressed air escaping through the mixed liquids.

It requires about one hour to charge, nitrate, and discharge the contents. During the nitration copious fumes of NO_2 are given off from the surface of the acid mixture. The condition of the charge and the degree of reaction are judged by inspection.

When the nitration is completed the contents are permitted to run out into the separating apparatus, which consists of a large leaden tank. The nitroglycerine, having less specific gravity than the waste acids and mixed by-products, collects on top. It is drawn off through a stop-cock into a second tank containing water. While the nitroglycerine is being run into this latter tank, compressed air is forced from below through the water, keeping it agitated. The effect of this is to "wash" the nitroglycerine and to keep the temperature between 60° and 86° F., which is of first importance. Its specific gravity being greater than water (1.6), it settles to the bottom of the tank as soon as the compressed air is shut off, and is drawn off from it for further purification. A small amount of nitroglycerine will be left in the wash-water; this is partially recovered by mixing with other washings and subsequent separations.

There remain also some slight traces of free acid; these

are removed by adding a small quantity of sodium carbonate in solution. The washing process is then repeated in a washing-tank of similar construction, agitating the liquid in a warm dilute solution of sodium carbonate by compressed air, repeating the washings and renewing the solution until the desired degree of purity is attained.

After it is thoroughly washed, it is filtered through flannel or felt, stretched on suitable frames, two frames being used, to remove all slimy and foreign particles which may have gotten into the liquid during the manufacture. A layer of dried salt is placed on the filters, to remove small quantities of water still in the liquid and to favor the rate of filtering.

The nitroglycerine is allowed to stand in a warm room for several days, and still a small quantity of water will rise to the top, and may be removed by skimming or absorption.

The waste acids and wash-waters are subjected to special treatment to recover the small quantities of nitroglycerine carried off in them, and to place the acids in such condition that, after properly "fortifying" them, they may be used again.

Physical Properties.—Nitroglycerine, made from chemically pure ingredients and at a temperature between 60° and 80° F., is a water-white oily liquid, without odor at ordinary temperature. Commercial nitroglycerine has a yellow color, more or less deep. When free from water it is transparent; the presence of water makes it milky and translucent.

It has a slightly sweet taste, and gives a burning sensation. It is very poisonous, and a very small quantity absorbed through the mouth, nostrils, or skin gives characteristic symptoms of giddiness, faintness, and severe headache; if the quantity be increased, these symptoms become more aggravated, producing rigor and unconsciousness. Robust and highly nervous persons appear to be specially susceptible to the effects described. Sometimes one never becomes immune to these effects, but, as a rule, the human system little by little adjusts itself so that workmen experience no unpleasant effects. The

headache effect is most often experienced by those not accustomed to handling nitroglycerine.

Nitroglycerine contracts about .08 of its volume in freezing, which it does at 3° to 8° C. (37° to 46° F.);¹ it does not melt from the frozen state until at about 11° C., or about 51° F.

Nitroglycerine is soluble in alcohol of above 90 per cent strength, ether, chloroform, benzine, concentrated sulphuric acid, glacial acetic acid, warm turpentine, methyl and amyl alcohols, carbolic acid, nitrobenzine, toluene, acetic ether, acetone, olive-oil, stearine oil, hot nitric acid.

It is insoluble in cold water, 50 per cent alcohol, carbon disulphide, cold turpentine, kerosene, caustic-soda solution, borax solution.

It is decomposed by cold hydrochloric acid, specific gravity, 1.2, slowly; hot ammonium sulphhydrate, hot iron chloride, 1.4 grams Fe to 10 c.c.

The presence of nitroglycerine may be detected by acting on the suspected liquid with a solution² of aniline in concentrated sulphuric acid. This gives a *purple color*, which turns green on the addition of water.

Another simple test is to absorb the suspected drop or quantity with blotting-paper. If it is nitroglycerine, it will not dry, and, when struck on an anvil with a hammer, it will explode. Lighted, it burns with a yellowish flame; placed on a hot metal plate, it explodes.

In the frozen state, nitroglycerine is less sensitive to shock than in the liquid state; but the process of thawing frozen nitroglycerine is a very dangerous one, and many accidents have resulted therefrom. It should never be attempted over

¹ According to Walke, at 3° to 4° C. (37° to 40° F.); according to Bloxam, at about 4° C. (40° F.); according to Munroe, at 39° to 40° F.; according to Guttmann, freezes at 8° C. and melts from the frozen state at 11° C.

A small per cent (0.5 to 3.) of nitro-benzine reduces the freezing-point very much, but diminishes the explosive effect also.

² 1 volume aniline to 40 volumes H₂SO₄, specific gravity 1.84.

a naked flame, or by direct contact with a solid in contact with a flame. The only safe way is to thaw over steam-pipes heated not higher than 50° C. (122° F.), or immersed in a water-tight vessel itself immersed in a vessel of water heated not higher than 50° C. (122° F.).

Nitroglycerine can be completely evaporated at a temperature of about 70° C. (158° F.). It evaporates slowly at lower temperatures; at 40° C. (104° F.) 10 per cent has evaporated in a few days. Washing for two hours with water at 50° C. (122° F.), with agitation by compressed air, 0.15 per cent of nitroglycerine is lost.

Although *frozen* nitroglycerine is very liable to explosion if brought over a naked flame or hot metal, *liquid* nitroglycerine is insensitive to flame. A lighted match plunged into liquid nitroglycerine will be extinguished without causing explosion; an incandescent platinum wire will be cooled down, the nitroglycerine only volatilizing.

If the liquid is ignited in the open air, it will burn quietly provided the mass is small; if it is large and the temperature is increased by a failure of the heat of the burning surface to be conducted off, explosion will take place when the temperature of the surrounding medium rises to 180° C. (356° F.).

Formerly, nitroglycerine was thought to be liable to undergo spontaneous decomposition, but, as now manufactured, such danger is very remote. If properly purified, there should be no tendency to decompose. When decomposition starts, it proceeds slowly and quietly, giving off NO₂ and CO₂ and forming crystals of oxalic acid; the escaping gases, some of which are held in the liquid, color it green. As the decomposition proceeds, the entire mass, after some months, is converted into a greenish, gelatinous substance, composed chiefly of oxalic acid, ammonia, and water. Decomposing nitroglycerine is, therefore, characterized by a *greenish* color. While in this state, it is more liable to explosion than when normal, and every care should be taken not to subject it to jar, blow, or shock; decomposing

nitroglycerine should be exposed to the open air, so that the heat of chemical action may be carried off.

All nitroglycerine should be tested from time to time for free acid with blue litmus-paper.

If heated above 45° C. (113° F.), decomposition will ensue, but below this temperature it may be kept in storage indefinitely without change.

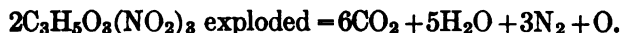
A mass of nitroglycerine heated above 180° C. will explode. It will explode by shock under certain conditions. If pinched between two rigid surfaces like metal or rock, it explodes; e.g., a small piece of blotting-paper saturated with a drop of nitroglycerine, struck by a hammer on an anvil, will explode at the point struck, but, as a rule, not beyond. A thin thread or sheet of nitroglycerine on a metal surface will detonate if struck with a piece of metal. A bullet fired into a mass of nitroglycerine will detonate it.

Shock, friction, and heating of all kinds must be carefully guarded against in handling and keeping nitroglycerine.

Nobel, in 1863, discovered that the highest type of explosion could be initiated in nitroglycerine by a small cap of fulminate of mercury. This marked an epoch in explosives, in that it for the first time established the fact that the *character of the explosion* is dependent upon the *character of the initial disturbance*. Nitroglycerine should, therefore, be fired by a cap of mercury fulminate if its full explosive force is to be developed, and for this purpose the cap should be in direct contact with the liquid. In the frozen state, it requires a powerful cap to detonate it.

Great care should be taken of cans or other receptacles which have contained nitroglycerine. The film of nitroglycerine left on the surface of such empty receptacles has caused disastrous explosions. All such receptacles should be immersed in an alkaline sulphide solution before being used for other purposes.

The explosive reaction for nitroglycerine may be given as follows:



One kilogram of nitroglycerine should give 1135 litres of gaseous products.

The temperature of explosion has been ascertained by experiment to be about 3000°C . The theoretical temperature, exploded in its own volume, is 6980°C .

The energy represented by 1 kilogram is about 6000 kilogram-meters. It is about eight times more powerful than gunpowder, weight for weight. Exploded in its own volume, it gives a pressure of about 164 tons per square inch.

Nitroglycerine was first used by Nobel in 1864 for blasting purposes. It proved to be a very dangerous explosive, on account of its liquid state and its "creeping" and "sweating" properties. Small masses could not be distinguished from water, and the detonation of a drop might explode huge masses, causing great destruction of life and property.

To avoid these dangers, Mowbray, of North Adams, Mass., made use of it in the *frozen state* in the construction of the Hoosac Tunnel. Not only were the dangers due to the liquid state avoided, but in the frozen state it is less sensitive to shock.

Nobel next resorted to the device of dissolving nitroglycerine in wood alcohol (15 to 20 per cent) for shipment. While in this state it is absolutely non-explosive, and can be recovered in its explosive form by adding 6 to 8 times its volume of water to the solution. While this made shipment safe, the danger of handling it in blasting, and for disruptive purposes generally, remained, and its use in the liquid state was discontinued abroad some years ago, and recently in America.

At present, nitroglycerine is only used in explosives as an ingredient of dynamites of various types and of smokeless powders.

If at any time it is necessary to store liquid nitroglycerine, it should be kept in earthen crocks, standing in copper vessels, and a layer of water should be kept on the nitroglycerine.

If the liquid show a green color at any time, the mass should be destroyed by explosion or by chemical action, any alkaline

sulphide solution being efficient for this purpose. "Sulphur solution," made by dissolving flowers of sulphur in a solution of sodium carbonate, is the solution used, as a rule, for this purpose. Whenever nitroglycerine is stored either in the liquid form or as dynamite, a sulphide solution should be kept on hand to pour over particles that may get on shelves or floor.

(c) Dynamites.

"Dynamite" is a term that has both a general and a specific meaning. As a general term, it includes all mixtures of nitroglycerine with solid substances, in which the latter hold the liquid nitroglycerine in absorption. The mixing may be done directly or indirectly through the medium of a solvent. The solid substance is called the *base* or *dope*. The base may be itself an explosive, or a combustible material, or entirely inert in the chemical reaction of explosion. In this sense, smokeless powders that have nitroglycerine as an ingredient partake of the nature of dynamite, but the name is used with reference to explosives designed for disruptive purposes only.

Berthelot divides dynamites into several classes:

1. Those having an inert base of silica, magnesium carbonate, brick-dust, tripoli, sand, etc., having little or no chemical action in the explosion, and act along physical lines to render the mixture safer by checking the transmission of molecular shock-waves, the harmonious propagation of which, through a homogeneous mass, gives rise to the explosive wave.
2. Those having an active base, which may be
 - (a) An explosive compound.
 - (b) A combustible base.
 - (c) A mixed base, consisting of a combustible and an oxygen-carrier.

The bases are modified to suit the work in hand; the nature of the explosion may be either *shattering* (local) or *propulsive*, the latter grading off into the slow-burning powders.

In a more special sense, the term refers to the first practical form of dynamite, namely, that in which liquid nitroglycerine was mixed with the infusorial earth called kieselguhr as the absorbent base.

The difficulties and dangers attending the use of liquid nitroglycerine have been referred to. In 1866 Mr. Alfred Nobel, in attempting to avoid these, hit upon the means of absorbing the liquid explosive into the mass of pulverized kieselguhr, an earth found in beds in various parts of the world, consisting of the silicious remains of infusorial life. This earth has marked absorptive properties, due to the cellular nature of the particles which constitute it, and, having absorbed a liquid-like nitroglycerine, it holds it tenaciously. Nobel, by making use of this property of kieselguhr, avoided the difficulties and dangers of transportation, handling and exploding nitroglycerine without materially impairing its power, and to this mixture he gave the name "*dynamite*." When carefully calcined the best kieselguhr will absorb over four times its own weight of nitroglycerine. The amount of nitroglycerine present in any case is regulated by the character of the work to be done; the highest commercial percentage is 75 per cent, and this is called "Dynamite No. 1." Dynamite "No. 2" has 50 per cent nitroglycerine; "No. 3," 30 per cent nitroglycerine. A little sodium carbonate is usually present to neutralize any free acids that may form.

The following is a summary of the steps taken in the manufacture of dynamite:

1. The kieselguhr is calcined in a reverberatory furnace.
2. It is ground between rollers.
3. It is passed through fine sieves.
4. It is dried.
5. It is packed in bags and stored in a *dry* atmosphere.
6. It must not contain more than 0.5 per cent of water.
7. Dry guhr is spread over the bottom of lead-lined troughs.
8. Nitroglycerine is poured over it and mixed thoroughly.

9. It is rubbed through sieves: 1st, 3 meshes to the inch; 2d, 7 meshes to the inch.
10. The bulk dynamite is pressed into cylinders about 1 inch diameter and 8 inches long. These cylinders are called "sticks" or "cartridges."
11. The cartridges are carefully wrapped in paraffined paper.

The sensitiveness of dynamite is increased very much by heat. According to Eissler, "at 350° the fall of a dime upon it will explode it."

It ignites at 180° C. (356° F.); at this temperature it will burn quietly, if free from pressure and not affected by jar, vibration, or extraneous force of any kind, otherwise it explodes.

A thin layer spread over a tin plate will evaporate the nitro glycerine if placed over a burner, but if the layer be more than one-quarter of an inch deep the dynamite is liable to explode.

At a temperature less than 180° C. the sensitiveness increases with the temperature and time exposed.

Exposed to gentle heat, dynamite undergoes no change. Heated at 100° C. for one hour, no change should take place. Heated rapidly to 220° C., it ignites and burns. If ignited it burns quietly when free, but if confined will explode. If a large mass of dynamite is ignited, the interior portion may be heated high enough to explode, being *confined* by the surrounding mass.

If exposed to high storage temperature for a considerable time the nitroglycerine is liable to "leak"; dynamite should be tested for "leaking" at the highest temperature to which it is liable to be exposed in storage.

When dynamite is exposed to a temperature below 12° C. the nitroglycerine has a tendency to freeze; and if it be lowered much below this, down, say, to 4° C., the nitroglycerine freezes, and in doing so separates from its base to a certain extent and does not always become absorbed again on melting. If solidly frozen it is very insensitive to shock. A frozen stick of dynamite may, however, be exploded by attempting to cut it or

chop it in two. It is dangerous to ram a frozen cartridge; forcing the frozen crystals over each other is apt to initiate an explosion; the violence of the explosion is much reduced in the frozen state.

While a stick of unfrozen dynamite may be ignited without danger, it is very dangerous to bring a frozen stick in contact with a naked flame or highly heated surface. It is only safe to thaw it in a covered vessel itself immersed in a water-bath.

Dynamite as a disruptive explosive is most efficient with hard, rigid material. With soft, yielding material it gives only a local effect. With such materials a slower acting explosive, like black powder or the modified dynamites described later, should be used.

A dynamite with an inert base containing less than 30 per cent of nitroglycerine will not explode. When the proportion of nitroglycerine is reduced below 30 per cent it is necessary to use an active base, either a mixture or compound (see Judson Powder and Blasting Gelatin).

Kieselguhr dynamite usually has a light-brown to reddish-brown color, and looks like brown sugar. It should not feel greasy to the touch, and the wrappers of dynamite sticks should show no evidences of liquid nitroglycerine on the inside. The outside of the stick when the wrapper is removed should be smooth, even, and compact; there should be no evidences of a pasty condition, or greenish spots. Broken across, the stick should present an even, granular surface on the cross-section, with no evidence of exuded globules of nitroglycerine.

The white deposit often seen on the outside of a stick of dynamite is not necessarily an indication of deterioration.

Kieselguhr dynamite is used at present chiefly in America. Dynamite No. 1 is used to charge submarine mines, and for military demolitions. According to Munroe, dynamite No. 1, exploded in its own volume, gives a pressure of 125 tons per square inch.

For rock-quarrying, tunnel-making, and blasting generally

there are many varieties of dynamites, particularly those having active bases, either explosive or combustible.

The following are some examples of American commercial dynamites:

GIANT POWDER (Dynamite No. 1).

Nitroglycerine.....	75	parts
Kieselguhr.....	25	"
Sodium carbonate.....	0.5	"

ATLAS POWDER (A).

Nitroglycerine.....	75	parts
Sodium nitrate.....	2	"
Wood-fiber.....	21	"
Magnesium carbonate.....	2	"

ATLAS POWDER (B).

Nitroglycerine.....	50	"
Sodium nitrate.....	34	"
Magnesium carbonate.....	2	"
Wood-fiber.....	14	"

SAFETY NITRO-POWDER.

Nitroglycerine.....	68.81	parts
Sodium nitrate.....	18.35	"
Wood-pulp.....	12.84	"

GIANT POWDER (No. 2).

Nitroglycerine.....	40	parts
Sodium nitrate.....	40	"
Sulphur.....	6	"
Resin.....	8	"
Kieselguhr.....	8	"

RENDROCK.

Nitroglycerine.....	40	parts
Potassium nitrate.....	40	"
Wood-pulp.....	13	"
Pitch.....	7	"

VULCAN POWDER.

Nitroglycerine.....	30.0 parts
Sodium nitrate.....	52.5 "
Sulphur.....	7.0 "
Charcoal.....	10.5 "

JUDSON POWDER.

Nitroglycerine.....	5 parts
Sodium nitrate.....	64 "
Sulphur.....	16 "
Cannel-coal dust.....	15 "

There is a dynamite made in England, in which the base is charcoal made from cork. This has a remarkable absorptive power, taking up as much as 90 per cent of nitroglycerine, and retaining it even if kept under water for a prolonged period. It is known in the market as "cork-dynamite."

Like all nitro-compounds, dynamites are more sensitive to shock at the higher temperatures.

Direct rays of the sun have the same effect as with other nitro-compounds, tending to decompose them.

Dynamite made from properly purified nitroglycerine should, however, keep indefinitely at ordinary storage temperature.

Water in contact with dynamite displaces the nitroglycerine. This principle is made use of in collecting nitroglycerine from dynamite for test. All dynamite which has been exposed to water is dangerous.

Dynamite requires a much more violent shock than nitroglycerine to explode it. Iron on iron, or iron on stone, will explode it, but wood on wood will not. It is more sensitive to shock in proportion as the percentage of nitroglycerine increases.

A small-arm bullet fired at short range into dynamite will explode it.

TABLE SHOWING THE PERCENTAGE OF NITROGLYCERINE CONTAINED IN THE DIFFERENT GRADES OF "ATLAS" POWDER, AND THE DISTINGUISHING MARKS OF CORRESPONDING GRADES OF "HERCULES," "GIANT," "ÆTNA," "HECLA," "JUDSON," AND "FORCITE" POWDERS.

Atlas (Standard).		Hercules.		Giant.		Ætna.		Hecla.		Judson.		Forcite.	
Brand.	Per cent. N. G.	Brand.	Per cent. N. G.	Brand.	Per cent. N. G.	Brand.	Per cent. N. G.	Brand.	Per cent. N. G.	Brand.	Per cent. N. G.	Brand.	Per cent. N. G.
E	20	No. 4	20	Extra	20	No. 5	15			R. R. P.	5 and under		
E+	27	No. 4 S	27	M	20	No. 4	20			F. F.	10	No. 3 E	20
D	30			F. F. F.	20	No. 4 X	25			F. F. F.	15	No. 3 D	25
D+	33	No. 3 S	33	X X X	27	No. 3 B	27	No. 3	20		20		
						No. 3	30	No. 3 X	27	Dbl. Ex.	27	No. 3 C	30
C	40	No. 2	40	No. 2 C	33	No. 3 A	33	No. 2 X	33	Tpl. Ex.	33	No. 3 B	32
C+	45	No. 2 S	45	No. 2	40	No. 3 X	35	No. 1	40			No. 3	40
B	50	No. 2 SS	50	No. 2 Ex.	45	No. 2 X	45					No. 3 X	45
B+	60	No. 1	60	New No. 1	50	No. 2 XX	50	No. 1 X	50			No. 2 X	50
A	75	No. 1 XX	75	No. 1	75	No. 1	60	No. 1 XX	75			No. 2 X	60
												No. 1	75

(d) Explosive Gelatin.

In 1875 Nobel introduced a new type of explosive—a mixture of collodion cotton and nitroglycerine—under the name of “blasting gelatin.” The chemical principle involved in this explosive is that a more complete combustion takes place with the mixture than with either ingredient; the excess of oxygen in the products of explosion of nitroglycerine supplying the deficiency in the explosion of nitrocellulose, causing the C to burn to CO_2 , instead of partly to CO; this additional chemical action greatly increasing the *heat*, hence the *volume* and *force* of the explosion. The proportions vary, but may be taken at about 90 per cent of nitroglycerine with about 10 per cent of nitrocellulose completely soluble in ether-alcohol. According to Berthelot the proportions of the mixture are 93 to 95 parts of nitroglycerine, 7 to 5 parts of collodion cotton. The mixing is done in troughs at a temperature of 122°F . with wooden spades, and when the mass is so gelatinized as to make it difficult to work with spades it is kneaded by hand, like bread-dough, until it has a smooth, even consistency. It is then removed and allowed to cool, finally the mass becomes a rather firm, compact, jelly-like substance, soft enough to be easily cut by a knife. The finished product is worked into cylindrical cartridges, but this cannot be done in presses as with ordinary dynamite. As a rule, the gelatinous mass is placed in an inclined cylinder in which an Archimedean screw revolves. The action of the screw is to force the gelatin to the upper end of the cylinder and out through a circular orifice in that end, forming a continuous “cable” or “rope” of the explosive. This cable is cut by a bronze knife into the lengths desired. These cartridges are wrapped with paraffined paper, the same as ordinary dynamite-cartridges.

This substance is the most powerful explosive known, having, according to Abbot's experiments, 17 per cent greater intensity of action than Dynamite No. 1. According to Berthelot, by theory, it should have 30 per cent more power.

Explosive gelatin is a yellow or light brown, gelatinous, elastic mixture, more stable than ordinary dynamite. It differs from ordinary dynamite, also, in that ordinary pressure does not cause the nitroglycerine to exude, and it is not affected by the action of water, except at the surface. One gram of mercury fulminate is required to detonate uncamphorated explosive gelatin. By adding to the mixture a small quantity of benzine, or, better, camphor (1 to 4 per cent), it is rendered insensitive to ordinary shock and friction, but at the same time it requires a more powerful primer to detonate it; the addition of camphor also raises the temperature of explosion to above 300° C.; if mixed with 10 per cent of camphor it fuses without explosion. The special primer required to detonate camphorated blasting gelatin consists of 60 parts of nitroglycerine and 40 parts nitrohydrocellulose. The initial shock required to detonate blasting gelatin is six times greater than that required to detonate ordinary dynamite. Owing to these causes blasting gelatin is far less sensitive to explosion by influence; the sensitiveness of blasting gelatin varies in a general way inversely as the quantity of nitrocellulose used in the mixture.

A cartridge of blasting gelatin placed in water will turn white on its surface, owing to the fact that nitroglycerine in the outer layer is displaced. The nitrocellulose remaining forms a protective coating to the rest of the mass.

At ordinary temperature it is much less sensitive than ordinary dynamite; in the frozen state it is very sensitive to shock, and, in this respect, the opposite of ordinary dynamite.

It burns in the open air without exploding, when small quantities are used.

It is very stable under the action of heat, keeping for days unchanged at 70° C., but its sensitiveness is increased by heat. Slowly heated to 204° C. it explodes.

The stability test is for 10 minutes, but it will often stand the heat of the test for from 40 to 60 minutes.

The action of blasting gelatin is too violent for many purposes, and modifications of it have been introduced. The

explosive gelatin, as made above, or a little thinner (using less nitrocellulose), is mixed with other substances, with a view to deaden the violence or prolong the duration of the explosive force, in the same manner as is done in ordinary dynamites. A large variety of these mixtures have been suggested; one of them is known as *Gelatin Dynamite*, and has the following composition:

Explosive gelatin.	65 per cent
Base.	35 " "

The explosive gelatin has only 3 per cent of nitrocellulose.

The base is a powder made up of 75 parts of sodium nitrate, 24 parts of wood-pulp, and 1 part of sodium carbonate.

Analogous to these is a class of explosives, in which nitrocellulose is mixed with oxidizers like the metallic nitrates, and the mass held together by some cementing matrix, such as paraffin, gums, resins, etc. There is a great variety of this class of explosives; they are of interest only historically, and in the sense only that it was through them that the present composite smokeless powders were evolved, although originally used largely for blasting purposes.

(e) Picric-acid Derivatives.

Picric Acid and the Picrates have been considered (see pp. 76 and 79). Recently certain derivatives of these compounds have come into use as charges for shells. The compositions of these explosives are kept secret and cannot be given. They were first exploited in 1869 by Brugère and Designolles in France, and Abel in England. The powders proposed by these consisted of a mixture of ammonium picrate and saltpetre.

Mellinite, used by the French as a shell-filler, is essentially picric acid alone or with other substances. Originally it was a mixture of picric acid and colloided nitrocellulose, later only fused picric acid was used, and Cundill says "there is some

reason to believe that nitrobenzol or a similar material is employed as well."

Lyddite is the English equivalent of mellinite.

The later forms of these shell-filler explosives, such as were used by the Japanese and Russians in the recent war, are thought to be either pure picric acid or a mixture of it with nitro-compound, of the aromatic series, as suggested by Cundill.

Much attention has been given to the use of high explosives in shell by the U. S. Army Ordnance Board, with results superior, it is thought, to those attained elsewhere.

The most successful explosives of this type in the United States are Maximite, Explosive D, and Picric Acid.

Mr. Maxim, in an article in the "Journal of the Military Service Institution" for November, 1901, gives some account of maximite. He says it "consists mainly of a novel picrate." Maximite is fusible. Shells are filled by melting it and pouring it into the cavity in the melted state. The Ordnance Board reports that the tests indicate that it is a suitable explosive for armor-piercing shell. It was used in the 12-inch A.P. shell in the Gathmann gun trials.

Explosive D is not fusible; it is used as a shell-filler by compression; this is considered a disadvantage, both because the density of charging is less and because application of pressure of such magnitude as is necessary to properly charge shell introduces a source of danger. Explosive D is, however, the least sensitive to shock of all the explosives named, and this is a very great advantage.

A high explosive for charging shell must fulfil many conditions, some almost contradictory, in order to be thoroughly serviceable.

The Ordnance Board, U. S. Army, enumerates the following requirements for high explosives for shell:

Safety and Insensitiveness.

1. Should be reasonably safe in the manufacture and free from very injurious effects on the operatives.

2. Must show a safe degree of insensitiveness in the impact machine.

3. Must withstand the maximum shock of discharge under repeated firings in the shell for which it is intended.

4. Must withstand the shock of impact when fired in unfused shells as follows:

(a) *Field Shell*.—With maximum velocity, against 3 feet of oak timber backed by sand. With remaining velocity, that of full-service charge at 1000 yards, against seasoned brick wall.

(b) *Siege Shell*.—With remaining velocity, that of full-service charge at 500 yards, against seasoned concrete thicker than shell will perforate.

(c) *Armor-piercing Shell*.—Against a 7-inch tempered steel plate in a 12-inch A.P. shell, with striking velocity just sufficient to perforate the plate.

Detonation and Strength.

1. Must be uniformly and completely detonated with the service-detonating fuse.

2. Should possess the greatest strength compatible with other necessary requirements.

Stability.

1. Must not decompose when hermetically sealed and subjected to a temperature of 120° F. for one week.

2. Should be preferably non-hygroscopic, and must not have its facility for detonation affected by moisture that can be absorbed under ordinary atmospheric conditions of storage and handling.

3. Must not attack ordinary metals used in projectiles and fuses to an extent that cannot be prevented by simple means.

4. Must not deteriorate or undergo chemical change in storage.

Charging Shell.

1. *Safety*.—Charging must not be attended with unusual danger, and should not require exceptional skill or tedious methods.

2. *Efficiency.*—It is very desirable that shell may be charged by pouring in the explosive in fused state, or by inserting the charge in the form of densely compressed blocks.

Supply.

It should be possible to obtain large quantities of it quickly and at reasonable cost.

The following table gives the data of tests made with the explosives that were favorably considered by the Army Ordnance Board:

Nature of Property.	Rend-rock, No. 400	Pieric Acid.	Maximite, 20 per cent.	Explosive D.	Gun- cotton Pellets.
Relative force for actual density of loading in shell referred to guncotton as unity.....	2.12	2.87	1.91	1.81	1.00
Specific gravity.....	3.62	1.70	1.55	1.64	1.40
Density of loading in shell...	2.54	1.66	1.58	1.31	0.73
Charge in pounds contained in 100 cubic inches.....	9.00	5.84	5.67	4.75	2.60
Cost of same charge (estimated).....	\$3.60	\$2.04	\$2.83	\$1.80	\$1.69
Method of charging.....	Melted	Melted	Melted	Bulk compression	Pellets, wax matrix
<i>Requirements.</i>					
1. Safety in manufacture....	Yes	Yes	Yes	Yes	Yes
2. Impact test.....	Yes	Yes	Yes	Yes	Yes
3. Shock of discharge in gun	Tested	Tested	Tested	Tested	Tested
4. Shock of impact (a), (b), (c) ¹	(a) “ (b) “	(a) “ (b) “ (c) “	(b) “ (c) “	(b) “ (c) “ Yes	(b) “ (c) “ Yes
5. Facility of detonation....	Yes	Yes	Yes	Tested	Yes
6. Relative strength in shell.	2.12	2.87	1.91	1.81	1.00
7. Stability (heat) test.....	Yes	Yes	Yes	Yes	Yes
8. Non-hygroscopic.....	Yes	Yes	Yes	Yes	15% H ₂ O
9. Non-action on metals....	Yes	Metals must be protected	Metals must be protected	Yes	Yes
10. Storage stability.....	Tested	Not tested	Not tested	Tested	Tested

¹ See page 164, Safety and Insensitiveness.

VI.

EXPLODERS.

THE essential ingredient of the explosive used in all exploders, primers, or caps is fulminate of mercury. The explosive used may require some adjustment of the quantity of fulminate in order to obtain an explosion of the proper order, or it may require some other ingredient to be mixed with the fulminate of mercury, such as chlorate or nitrate of potassium, sulphide of antimony, etc., but, as a rule, fulminate of mercury is present.

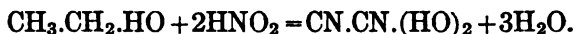
The ingredients of cap and primer composition vary with the kind of explosive that is to be exploded. Dynamite, gun-cotton, picric acid, and progressive explosives each require a different cap or primer composition. Especially is the nature of the initial blow important in progressive explosives. If the primer's flame be lacking in kind or amount some of the powder may not be burned in the gun; if it be excessive, it will be burned too soon and give too great pressures. Much attention has been given to this question. Experiments have been conducted to determine the primers best adapted to different explosives—to ascertain for each explosive the proper energy, heating effect, shape, size, and duration of the flame of the cap composition. Photography has been introduced, and it has been found that the photographs of cap and primer flames are characteristic in each case.

There are fulminates of silver and gold, but they are too sensitive to have any uses in military explosives.

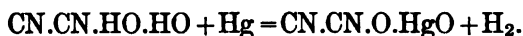
Mercury fulminate is formed by treating metallic mercury with nitric acid and alcohol.

The chemical reactions which take place are not fully agreed on among chemists. Bloxam gives the following explanation:

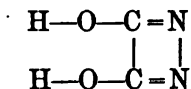
When nitric acid acts on alcohol several products are obtained, among which are *nitrous acid* and some *hydrocyanic acid* (HCN). The formation of the CN group in this reaction may be explained by the tendency of nitrous acid to substitute N for H₃ in organic compounds, and it might be expected that the action of nitrous acid on alcohol would be



The group CN.CN.(HO)₂ is too unstable to exist separately. This is the hypothetical *fulminic acid*. If it be assumed to exist in the course of the reaction, its production in the presence of mercury would, under the usual laws governing chemical changes, exchange its hydrogen for mercury, in accordance with the following reaction:

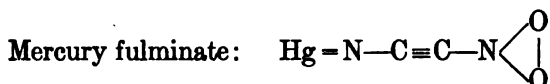
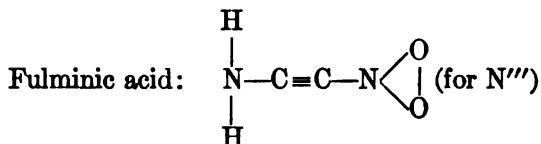


The structural formula (following Bloxam) may be represented as follows:

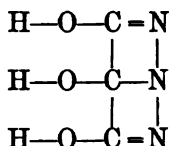
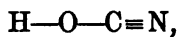


According to Guttman, Kikuli demonstrated, with a fair amount of accuracy, that fulminate of mercury should have the following rational formula: C(NO₂)(CN)Hg. He bases his conclusions on the reactions of fulminate of mercury with chlorine, bromine, and hydrogen sulphide. This would suggest the

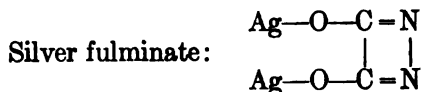
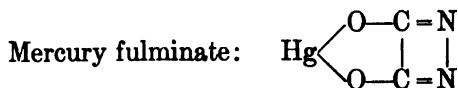
following structural formulas for fulminic acid and mercury fulminate:

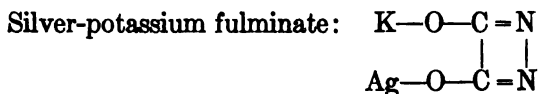
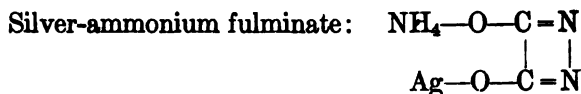


The assumption of a fulminic acid is supported by the actual existence of a mono- and tri-hydroxide of CN. The mono, CNHO, *cyanic acid*, a colorless liquid, specific gravity 1.4, and (CN)₃(HO)₃, *cyanuric acid*, a crystalline solid, a tribasic acid, forming salts with metals, corresponding respectively to the structural formulas



It is reasonable to assume that an intermediate hydroxide exists having two HO groups. Moreover, while the acid has not been separately produced salts, double, acid, and normal, corresponding to a bibasic acid have been produced, some of which are the following:





The manufacture of fulminate of mercury is conducted as follows:

Mercury and nitric acid (specific gravity 1.38) are mixed in a glass carboy in equal parts by weight. The mercury dissolves in the nitric acid and, when completely dissolved, the contents are allowed to cool; it is well shaken to secure uniformity of product, and then this solution is emptied into a second carboy which contains 10 parts of ethyl alcohol.

The second carboy is kept at a temperature above 60° F., and is connected with a series of receivers which stand in a trough through which water circulates. The pipe from the last receiver leads into a condensing chimney or tower.

After a few minutes the reaction begins in the second carboy, the liquid boils, and white vapors of nitric and acetic ether, aldehyde, carbonic acid, hydrocyanic acid, and some volatile compounds of mercury rise and pass off through the series of conducting pipes and receivers to the condensing tower. As the action proceeds the color of the vapors change from white to the red fumes of nitric peroxide.

In about fifteen minutes the crystals of fulminate of mercury separate from the solution in the second carboy in the form of small gray-colored needles. As soon as the reaction is completed the contents are allowed to cool, and are then poured out on a cloth filter stretched on a wooden form. These contents are then washed with pure water, until the washings show no trace of acid when tested with blue litmus. The filter is then placed in a drying atmosphere, out of the direct rays of the sun, and allowed to dry until the mass of fulminate contains only 10 to 15 per cent of water. The yield is

about 125 parts of fulminate of mercury to 100 parts of mercury. Theoretically there should be a yield of 142 parts per 100 parts of mercury. Great care must be exercised that no particles of fulminate are scattered about; any suspicious particles should be treated with sodium-sulphide solution.

The principal product is usually made up in packages containing 120 grains. It is put up with about 15 per cent of water and hermetically sealed, to prevent evaporation, as it is much more sensitive to shock and friction in the dry state.

When it is necessary to dry it for use in caps and detonators great care must be exercised. The temperature must be kept below 104° F., and the dry fulminate handled with the greatest care.

Pure crystals of fulminate of mercury have a yellowish-white shade. The gray color of the commercial fulminate is due to small particles of unconverted mercury. The pure fulminate is obtained by boiling in a large volume of distilled water, drawing off the hot liquid from which the pure fulminate crystallizes on cooling in the form of a yellowish-white, silky mass. This, examined under the microscope, appears as groups of crystals. The fine crystals are more desirable for use in detonators than the coarser ones. Mercury fulminate should not be kept in a stoppered bottle, especially not one having a glass stopper, as the friction of removing and inserting the stopper might detonate a particle of fulminate caught in the neck of the bottle and transmit the explosion to the whole mass. A moderate blow of a hammer causes it to explode with a bright flash and gray fumes of mercury. It is detonated if touched with a wire heated to 195° C. or by an electric spark, by contact with strong sulphuric or nitric acid, or sparks from metals or flint. Its specific gravity is 4.42. The volume of the gases evolved is 1340 times the volume of the solid fulminate at ordinary temperatures and pressures; this would be greatly increased by the temperature of the explosion. The explosive nature of the fulminate is due to the fact that the molecule

contains an oxidizing group (HgO_2) and a cyanogen (combustible) group (CN_2).

Heated slowly it explodes at 305°F. (152°C.); heated rapidly it explodes at 368°F. (187°C.).

The nature of the surfaces between which the fulminate is confined when struck has an effect on its explosion; between hard rigid surfaces, like iron or steel, the explosion is certain; between soft metal surfaces, like lead, not so certain; between wooden surfaces, doubtful.

The slower the crystallization the larger the crystals, and the larger the crystals the more sensitive is the product.

When moistened with 5 to 30 per cent of water the sensitiveness is greatly reduced; if struck in this state by a hammer on iron, only that portion directly between the surfaces will explode. The explosion of a quantity of dry fulminate in contact with wet fulminate will explode the latter, even if immersed in water.

Fulminate may be subjected to high pressure without explosion, *if pure*; if sand or grit be present, the slightest pressure may explode it.

Fulminate of mercury is used very little, except in caps and primers. It often has mixed with it other substances, such as potassium chlorate, sulphide of antimony, powdered glass, etc., to modify the nature of the explosive blow, producing a prolonged action and a penetrating heat which enters deep into the mass of the explosive. The addition of oxidizing substances, like potassium chlorate, serves to increase the heat, both because it is an endothermic substance and because the oxygen it supplies serves to burn the CO of the products of combustion of mercury fulminate to CO_2 , and thus still further increases the heat. Powdered glass is often added to increase the sensitiveness to percussion. Sulphide of antimony also increases sensitiveness, and it combines with potassium chlorate, producing heat and prolonging the action of the fulminating mixture.

The heat of formation for one equivalent, that is, a weight proportional to the weight of a molecule of mercury fulminate,

(284 grams) is $-62,900$ cal. Its heat of combustion in an inert atmosphere is $+116,000$ cal. for constant volume and $114,500$ cal. for constant pressure. This would raise the products of explosion to 4200°C .

The explosive reaction is



One gram of it should yield 235.8 cubic centimetres of gas at 0°C . and barometer of 76 centimetres. One equivalent (284 grams) should yield 66.7 litres of gas.

It is to be noted, particularly, that the products of explosion are simple gases, except CO , and therefore dissociation does not take place in a marked degree.

The effect of mixing mercury fulminate with an oxidizer, as is done in some cap compositions, is noted in the following reaction:



The heat evolved is $+258,000$ cals., almost twice that for pure fulminate, but the initial blow is greatly prolonged, due to dissociation and recombination of CO_2 and KCl .

With nitre the explosive reaction is as follows:



corresponding to $+227,400$ cals.

Exploding in its own volume mercury fulminate gives a pressure of $28,750$ kgm., as compared with $12,376$ kgm. for nitroglycerine and 9825 kgm. for guncotton.

The great value of mercury fulminate as an exploder is due to this enormous pressure, and to the fact of its suddenness, owing to the absence of dissociation; the pressure is, therefore, nearly that due to explosion in the volume of the original solid, which, relatively, is very small on account of the high specific gravity of mercury fulminate (4.42). The crushing effect on

the molecules of an explosive in contact with mercury fulminate is overpowering, and accomplishes the disruption of the bonds holding the atoms in the molecules; the atoms, once thus released, enter into new combinations, according to their affinities under the new conditions.

Caps and primers for progressive explosives require a more prolonged blow than that given by pure fulminate. It is, therefore, the usual practice to mix nitre or potassium chlorate for this purpose. Munroe gives the following directions for making composition for percussion caps:

100 parts of dry fulminate are rubbed to a powder with 30 parts of distilled water, 50 to 60 parts of potassium nitrate, and 29 parts of sulphur.

The rubbing is done on a marble slab, using a wooden spatula.

This mixture is dried sufficiently to admit its granulation.

It is then forced by pressure into copper caps and covered with a layer of varnish or of tinfoil, to protect it from dampness. The varnish used may be a solution of gum mastic in turpentine.

The caps are finally dried by a gentle heat and packed in boxes.

Primers for detonating explosives, for purposes of demolition or destruction, are made of pure fulminate of mercury. Such primers, as a rule, are electric, although there is one type made for use with time-fuses.

The United States Navy electric primer, according to Munroe, consists of a copper case made in two parts. The lower part is a No. 36 metallic cartridge-case. The upper part is a copper tube, open at both ends, which has been cut from a No. 38 metallic cartridge-case. A thread is pressed on each of these parts, so that the upper part or cap screws nicely on the lower part. The lower part is filled with fulminate of mercury up to the lowest thread of the screw. The top part is filled with a cement plug made of sulphur and glass, through which the lead-wires or primer legs pass to connect the bridge with the wires leading to the battery. When the fulminate is dry



the spaces in the lower case and the cap are filled with pulverulent dry guncotton, and then the parts are screwed together. The lead-wires should be long enough to protect the ends of the main conductor wires from destruction by the explosion, say 6 to 10 feet in length.

The bridge is practically the same for all primers. It consists of a piece of platinum-iridium alloy, about one-quarter inch long and .001 to .003 inch in diameter. Its resistance should be (bridge and short leads), cold, 0.3 to 1 ohm; hot, 0.45 to 2 ohms. Insulation resistance between conductor and case, 1 megohm. Strength of current to fire, 0.3 to 0.8 ampere. Usually a small wisp of dry guncotton is placed about the bridge; next to this is placed fine gunpowder for firing progressive powder-charges, or mercury fulminate for high explosive charges. The bridge is soldered to the bared ends of the lead-wires.

Commercial detonating-primers are made on the same general principle. A drawn copper tube, closed at one end, is used for the lower part of the primer. The upper tube contains a wooden plug sealed with sulphur, which carries the legs connecting the bridge with the leading wires.

A modification of these electric primers is made in which the wooden plug is omitted, leaving the mouth open for inserting a time-fuse train. In using a time-fuse insert the end so as to *touch the fulminate in the lower tube*, then crimp upper tube tightly down on time-fuse with pincers or crimpers.

The electric primer is the safest, simplest, cheapest, and most effective means of firing charges of high explosives; it is the only means used of firing separate charges simultaneously, or a single charge at a distant point, or at a required moment, or under water.

Different grades of commercial primers or blasting-caps are known to the trade. They are specified as single, double, triple, quadruple, and quintuple, etc., forcecaps. The single force contains 3 grains of fulminate of mercury, and the other grades contain each 3 grains more than the next lower grade. The primer composition consists, as a rule, of 75 parts of fulminate

of mercury and 25 parts of potassium chlorate pressed tightly into the lower tube; sometimes a little gum dissolved in alcohol is added to make the mass more coherent. The function of potassium chlorate, sulphur, nitrates, etc., in exploders has already been explained.

Blasting-caps are tested by inserting the cap in a cork with the base of the cap flush with the end of the cork, placing the cap with base resting on a piece of wrought iron, No. 14 A. W. G., supported on block under its four corners. An efficient cap should blow a clean hole through the iron.

The standard army electrical primer for high explosives consists of the following details:

1. A wooden plug grooved longitudinally on opposite sides to receive the lead-wires, and cannellured around the middle.

2. The lead-wires (of No. 18 A. W. G. copper wire, with braided and paraffined cotton insulation) are pressed into the grooves, half-way in one groove, then in the circumferential cut around half-way to the opposite groove, then longitudinally to the end of the plug, each wire leaving the plug in the side opposite to that on which it entered. The inside ends of the wires are bared, scraped, cut to a length of about 0.1", tinned and resined, soldered to the fine wire bridge, and bent slightly toward each other.

3. This plug is covered with a cylindrical cap with a stout shoulder at one end and having a small hole for the passage of the lead-wires. The cap fits the plug closely. The plug smeared with glue is forced into the cap until the end of the plug abuts firmly against the shoulder, leaving a chamber around the bridge to receive the priming.

4. The priming-chamber filled with mercury fulminate (4 grs.) is closed by a paper disk held in position by a drop of collodion.

5. The bridge is made of fine platinum wire (.0025" diameter, electrical resistance 3 ohms to the inch). This bridge will carry 0.1 to 0.15 ampere without heating, and this current may be used for testing; for firing, a current of about 0.5 ampere should be used; the length of the bridge is $\frac{3}{4}$ -inch.

6. The body of the primer is made of a second copper cylinder closed at one end. It contains 20 grs. of fulminate of mercury, held in place by a paper disk secured by a drop of collodion. The body fits over the cap and is pushed up over it and crimped into the wood near the top.

The completed primer is 1.4-inch long. As soon as finished it is dipped into melted Japan wax, which gives an even waterproof coating.

The electrical resistance of the completed primer is between 0.7 and 0.8 ohm.

VII.

SERVICE TESTS OF EXPLOSIVES.

General Remarks on Tests.

FROM what has gone before it will be understood that it is of great importance that all explosives made by the action of nitric acid should be free of all impurities, especially of free acids used in their manufacture and of by-nitro-substances resulting from the action of nitric acid on the raw material which may not itself have been absolutely pure. If any of these remain in a nitro-explosive it is liable to decompose in course of time, especially if it be exposed to temperatures above 90° F:

All high explosives are, therefore, subjected to certain standard tests with a view to determine their stability, and especially the probability that they will not decompose in storage.

Heat of sufficient degree will decompose all nitro-compounds, and even when the heat is comparatively low it will decompose nitro-explosives if they be subjected to it for a long enough time, the time required to initiate decomposition being shorter as the temperature is higher.

It is assumed that the time required to cause incipient decomposition of a nitro-explosive is a measure of its stability in storage. Experience has shown that if a nitro-explosive will withstand the action of a certain temperature for a certain time its stability in storage may be assumed. These temperatures and times have come to be accepted as standard tests.

There are many different stability heat-tests which have been suggested by different experimenters (see *Journal American Chemical Society*, March and June, 1903; and *Journal U. S. Artillery*, September–October, 1903), but only three will

be described. One known as the potassium-iodide-starch test, another as the litmus test, or 135° C. test, or German test; and the third as the U. S. Ordnance 115° C. powder-test. The first is used with all nitro-explosives, the 135° C. German test is used with nitrocellulose explosives, the 115° C. U. S. Ordnance test is at present used only with nitrocellulose powders.

In the potassium-iodide test the length of time is noted that is required to discolor a small test starch-paper saturated with potassium iodide by the nitric oxide liberated from the explosive by heat. In the litmus test the time is noted that is required to redden a litmus-test paper by fumes of NO_2 . In the Army 115° C. test the rate of loss of weight of the sample is noted.

Before the heat-test is begun, preliminary tests for free acids should be made with blue litmus paper. The explosive in pulverulent state is placed in a test-tube (about 25 c.c.), the tube is then half filled with distilled water, closed with cork and shaken well; the liquid is allowed to settle; the supernatant liquid is decanted and tested with blue litmus or methyl-orange.

Nitrocellulose manufactured for use in making smokeless powder must also be examined for the presence of free alkali in the same way, using phenolphthalein as the color indicator, and all nitrocelluloses are tested for the presence of mercury chloride in small quantity.

Apparatus Required for the Potassium-iodide-starch Test.

The apparatus required for making the potassium-iodide-starch test consists of a glass or copper globe or cylinder water-bath about 8 inches in diameter, with an aperture of about 5 inches; the bath is filled with water to within a quarter of an inch of the top edge. The aperture is closed by a loose cover of sheet copper about 6 inches in diameter. The globe rests on an ordinary iron tripod, so that the bottom of the globe is about 10 inches above the plane of the feet of the tripod.

A Berzelius alcohol-lamp is placed under the globe. The cover has four to eleven holes: one in the center for a thermometer fitted into a rubber stopper; five to ten at equal distances around the circumference to receive test-tubes, each containing a sample of the explosive to be tested. The test-tubes after being carefully cleaned and dried are closed by clean corks, each carrying, through a hole bored in, it a glass rod with platinum-wire hook on the lower end; this hook during the test supports the potassium-iodide-starch test-paper. The test-tube corks are discarded after one test. The test-papers should be obtained from a standard source, as the value of the test depends chiefly on the uniformity and proper degree of sensitiveness of the test-papers. In case of emergency the potassium-iodide-starch test-paper may be made as follows:

Forty-five grains of white maize starch (corn flour), previously washed with cold water, are added to $8\frac{1}{2}$ ounces of distilled water, the mixture is stirred, and boiled for 10 minutes.

Fifteen grains of pure potassium iodide (crystallized from alcohol) are dissolved in $8\frac{1}{2}$ ounces of distilled water.

The two solutions are thoroughly mixed and allowed to cool.

Strips or sheets of white filter-paper, previously washed with water and redried, are dipped into the solution and allowed to remain in it for at least 10 seconds; they are then allowed to drain and dry in a place free from laboratory fumes and dust.

The upper and lower margins of the strips are cut off.

The paper is preserved in well-stoppered bottles *and in the dark*.

Freshly made and suitable paper should give no discoloration if touched with a glass rod holding a drop of acetic acid. When a brownish or bluish spot appears from acetic acid so applied the paper should be rejected. Often an exposure of

one hour to bright light will destroy a set of test-papers. Papers over a month old are apt to be untrustworthy.

(a) **Dynamite, Nitroglycerine, and Explosive Gelatin.**

Dynamite.—If dynamite is to be tested the nitroglycerine must be extracted from the base. To accomplish this, advantage is taken of the fact that water will displace nitroglycerine from such mechanical mixtures as kieselguhr dynamite. The further test then becomes one simply of the nitroglycerine.

To Extract Nitroglycerine from Kieselguhr Dynamite.

A funnel, about 2 inches across, is arranged so as to filter into a small beaker. About 300 to 600 grains of dynamite finely divided are placed in the funnel, which has previously been loosely plugged by some asbestos wool. The latter should have been recently heated to white heat and allowed to cool.

The surface of the dynamite is smoothed off carefully by means of a flat-headed glass rod or stopper and some clean, washed and dried kieselguhr is spread over it to the depth of about one-eighth of an inch. This top layer of kieselguhr is then carefully and evenly saturated with distilled water by a fine jet from a water bottle. As soon as the first water has been absorbed into the mass of dynamite more is added. This is continued. The displaced nitroglycerine will, after some time, begin to drop into the measure below the funnel. The operation is discontinued when enough nitroglycerine has been collected to allow 50 grains for each test tube.

The Potassium-iodide-starch Heat-test.

Nitroglycerine.—The water-bath of the potassium-iodide-starch testing-apparatus is brought to 160° F. (71° C.) and maintained at that temperature, being regulated by the thermometer which should be immersed about 2½ inches in the

water. The source of heat should be carefully watched, and at no time should the temperature of the bath rise or fall more than 1° F. from 160° F. Fifty grains of nitroglycerine are placed in each test-tube and carefully weighed, being careful not to get any on the sides of the test-tube; this may be done by using a suitable dropper or glass tube.

A piece of test-paper is taken with the pincers and laid down on a piece of clean filter-paper. The test-paper is held in place by the end of a glass rod which has been thoroughly cleaned, heated, and cooled. A small hole is made in the test-paper with the point of the pincers opposite the middle of one end of the paper and about 0.2 inch from the edge. The test-paper is taken up with the pincers, the platinum hook inserted through the hole just made, the hook bent with the pincers until the throat of the hook is closed tightly on the paper, so that it will stand stiffly up when the paper is held vertically above the glass rod. The glass rod with test-paper is placed carefully aside under a bell glass or other protecting cover, where it will be protected from fumes and dust. In the same way the other test-papers are prepared.

A solution of pure glycerine and distilled water, in the proportion of 1 to 1, is prepared.

One of the test-papers is taken, held with the paper up, and a drop of the glycerine solution is placed on each of the lower corners of the test-paper, as held; the paper should absorb this evenly about half-way to the opposite upper edge, as held, leaving a distinct line about midway between the moistened and the unmoistened parts. One of the test tubes is placed in the bath through one of the apertures in the cover and is immersed until the sample is below the surface of the water. The test-paper moistened with glycerine is placed in the test-tube, and the glass rod is moved through the cork until the line between the moistened and unmoistened parts of the test-paper is about five-eighths of an inch above the upper surface of the cover. This time is recorded. The same is done with each of the other two test-papers. The line between

the moistened and unmoistened parts of each test-paper is watched carefully, and the exact instant that a *faint brown color*¹ appears on this line of demarkation on each test-paper is recorded. This completes the test.

The nitroglycerine under examination will not be considered "thoroughly purified" unless the time elapsed between the insertion of the test-paper and the appearance of the brown color is at least fifteen minutes. The average of the records of all the tubes will be taken.

Explosive Gelatin.—If explosive gelatin is under examination a sample of 50 grains is intimately incorporated with 100 grains of French chalk, using a wooden pestle in a wooden mortar. The French chalk should be of good commercial quality; it should be thoroughly washed with distilled water, dried in a water-oven, and then exposed to moist air under a bell jar until it has taken up about 0.5 per cent of moisture. It should then be placed in a glass-stoppered jar for use.

Each test-tube is filled with this mixture to a depth of $1\frac{1}{4}$ inches, the tube being gently tapped on a table to insure a proper degree of settling.

The heat-test is then conducted as explained for nitroglycerine. Explosive gelatin will not be considered as serviceable unless the average time of the test is at least ten minutes.

Explosive gelatin is subjected also to a liquefaction and exudation test as follows:

Liquefaction Test of Explosive Gelatin.

A cylinder is cut from the cartridge having its height equal to its diameter, care being taken to have the ends cut flat and true.

This cylinder is placed on a piece of filter-paper on a smooth, clean board, and secured to the board by an ordinary pin forced through it along its axis into the board.

¹ In order to detect this color promptly, the water-bath should be so placed that a bright reflected light shall fall on the papers.

It is exposed in this condition for 144 consecutive hours to a temperature ranging from 85° to 90° F.

The original height of the cylinder should not decrease more than one-fourth, and the upper cut surface should retain its flatness and sharpness of edge.

Exudation Test of Explosive Gelatin.

There should be no separation of nitroglycerine in the liquefaction test or under any conditions of storage, transport, or use, or when the explosive is subjected three times in succession to alternate freezing and thawing.

(b) Guncotton.

Loose-fiber Guncotton.—The material is dried at a temperature not greater than 40° C. to constant weight; then exposed on trays to the air in a room free from fumes, until from 1 to 2 per cent of moisture has been absorbed. It is then gently rubbed through a ten-mesh sieve to insure uniformity of division, being careful that it does not come in contact with the hands or any piece of apparatus not perfectly free from any trace of acid or alkali. 1.3 grams are weighed out and placed in a test-tube 5½ to 6 inches long and not less than ½ inch internal diameter.

The potassium-iodide-starch test is conducted as explained for nitroglycerine, except that the water-bath is heated to 150° F. (65.5° C.). The test-papers, prepared as already explained, are inserted in the test-tubes,¹ and the papers adjusted in the tubes so that the line dividing the dry and moist portions of the test-paper is on a level with the lower edge of the film of moisture which is deposited on the side of the tube soon after inserting it in the bath.

¹ The standard water-bath for nitrocellulose holds ten tubes; it is long and narrow to prevent heating the upper part of the tubes as much as possible. Tubes are immersed 2½ inches in the bath.

Nitrocellulose intended for the manufacture of smokeless powder must not show a brown color in less than 40 minutes (Army), (Navy, 30 minutes) at 150° F. (65.5° C.).

Blocks or Disks.—Guncotton for demolition purposes is issued in the form of compressed pulp, in disks or blocks. This form of guncotton is prepared for the heat-test as follows:

Sufficient material to serve for two or more tests is removed from the center of a block or disk by scraping, and reduced to a fine powder by rubbing between pieces of clean, dry filter-paper. This is spread out in a thin layer upon a paper tray about 6 by 4½ inches, which is then placed inside a water-oven, kept as nearly as possible at 120° F. for 15 minutes, the door of the oven being left wide open. The tray is then removed and exposed to the air of the room for two hours; during this time the material is rubbed on the paper tray with a clean glass rod and reduced to a fine and uniform state of division.

The temperature of the water-bath is the same as for fiber guncotton (150° F.).

There should be no brown color within 10 minutes.

Poacher Sample.—In case the sample is taken during the manufacture of nitrocellulose, it is taken after the poaching and after having been thoroughly washed in pure, cold water. The sample is pressed dry in a hand-press and rubbed in a clean cloth until finely divided, being careful not to let it come in contact with the hands.

(c) Smokeless Powder.

The sample should be prepared by cutting into slices 0.02 inch thick. These slices are exposed to the air for at least 12 hours.

The test-tube sample consists of 1.3 grams.

The usual potassium-iodide test is followed, except that the temperature is considerably higher for simple nitrocellulose powders, being 100° C. (212° F.) instead of 65.5° C. (150° F.).

Each sample must stand this temperature without showing a brown line for 10 minutes.

Powders containing nitroglycerine should stand the test at 65.5° C. for 20 minutes.

The British Government specifications prescribe the following times and temperatures for the potassium-iodide test:

- | | |
|---|----------------------------------|
| 1. Nitroglycerine. | 15 minutes at 160° F. (71° C.). |
| 2. Dynamite. | 15 " " 160° F. (71° C.). |
| 3. Explosive gelatin. | 10 " " 160° F. (71° C.). |
| 4. Smokeless powders with
nitroglycerine. | 15 " " 180° F. (82° C.). |
| 5. Guncotton. | 10 " " 170° F. (76.6° C.). |
| 6. Colloided pyrocellulose. . . | 15 " " 180° F. (82° C.). |

The German 135° C. Test.

Two and five-tenths grams of the sample to be tested are dried at the ordinary temperature of the laboratory for 12 hours and placed in a strong test-tube. A piece of blue litmus is placed in the tube about a half-inch above the sample, the paper being folded lightly so as to give the folds sufficient elastic power to hold the paper in place by pressure against the sides of the tube. The tube is lightly closed by a cork with a hole 0.15 of an inch in diameter bored through it, and so placed in a bath of boiling xylol (the boiling-point of which is 135°) that only 6 or 7 mm. project above the surface.

Examination of each tube is made each five minutes after twenty minutes have elapsed. In making this examination the tube should be withdrawn only half its length and quickly replaced.

Two tubes are used in each test, and there must be no failure in either tube.

Three observations are made: (1) Time of *complete* reddening of the litmus-paper; (2) time of appearance of brown nitric-oxide fumes; (3) time at which the sample exploded.

Stable explosives should give the following times:

	Litmus not Reddened in	No Nitric Fumes in	No Explo- sion in
Uncolloided nitrocellulose.	30 min.	45 min.	5 hrs.
Pure nitrocellulose powder.	1 hr. 15 min.	2 hrs.	5 hrs.
Nitroglycerine powders.	30 min.	45 min.	5 hrs.

For the results to have value they should be compared with that of a known stable explosive of the same kind, under the same test by the same operator, using the same test-paper.

Uncolloided nitrocellulose should be well shaken down in the tube by tapping, or lightly pressed down.

The U. S. Army Ordnance 115° C. Test.

(For nitrocellulose powders.)

Whole pieces of powder are carefully weighed on watch-glasses and then heated in an air-bath kept at 115° C. + or - ½° for 8 hours. The sample is then removed, allowed to cool in a desiccator, and reweighed. This is repeated six times on six separate days. At the end of this time the total loss of weight should not exceed 8 per cent, if the powder is stable enough for military purposes.

The air-bath may be maintained at 115° by filling the walls of the oven with a properly proportioned mixture of xylol and toluol. A reflux condenser prevents loss of the liquid by evaporation.

The temperature, 115° C., is the one that most clearly differentiates the decomposition of good powders from bad ones in a reasonable time limit. If a lower temperature is used, it requires too long a time to establish trustworthy data; if a higher temperature is used, the curves plotted to show the rate of loss of weight of good powders are not so clearly separated from those plotted to show the same for bad powders.

The following advantages are claimed for this test:

1. The powder is tested in its natural condition; the same in which it is stored or used.
2. It shows *all* products of decomposition; others show only *acid* or nitrogen losses by decomposition.
3. It shows the decomposition of other nitro-compounds than nitrocellulose which are often present in powders, and shows the effect of these on the decomposition of the powder.
4. It shows the effect on the stability of powder of added substances, placed there to mask stability tests; the effect of volatiles which may set up local decomposition; traces of nitric acid; decomposition of the nitrocellulose due to saponification by water, alkalies, carbonates, etc.
5. It shows quantitatively the progress of all decompositions.
6. It is a simple test, and requires only simple apparatus to make it.

The following are the latest specifications (July, 1906) proposed for powders for cannon, and for nitrocellulose for powders or other purposes used in the United States service.

Ballistic Test.

(a) *For Powder Passing the Physical Test.*—Determine the charge to give a pressure approximately 10 per cent greater than the service pressure corresponding to the service velocity for the caliber as given in the table on pp. 188, 189.

Fire at least three rounds with this charge; if the variation in the muzzle-velocity exceeds ± 1 per cent of the mean velocity of all of the shots considered, or the variation in pressure exceeds ± 5 per cent of the mean pressure for the same shots, three charges of identical weight will be fired to give approximately the service velocity and pressure. If the variation from the mean velocity and pressure for these rounds exceeds that stated above the powder will not be accepted.

STANDARD DATA OF POWDERS FOR U. S. ARMY CANNON.

Guns.	Powder.			Weight of Projectile.	Muzzle-velocity.	Maximum Pressure.	Weight of Lot.	Weight of Ballistic Sample.
	Kind.	Approximate Weight of Charge, Including Igniter.	Weight of Igniter.					
		Lbs.	Oz.	Lbs.	Feet per sec.	Lbs.	Lbs.	Lbs.
FIELD-, MOUNTAIN-, AND SIEGE-RIFLES, HOWITZERS AND MORTARS.	Nitrocellulose...	2½	½	1	1,800	27,000	2,000	2
	Nitrocellulose...	2½	½	2	1,313	13,000	2,000	2
	Nitrocellulose...	7	*½	15	920	18,000	5,000	5
	Nitrocellulose...	6.75	*½	12.5	750	13,500	5,000	5
	Nitrocellulose...	26	*½	13	1,700	33,000	10,000	15
	Nitrocellulose...	18	*½	13.5	1,685	35,000	7,000	10
	Nitrocellulose...	18	*½	13.5	1,685	35,000	7,000	10
	Nitrocellulose...	28	*½	20	1,550	35,000	10,000	15
	Nitrocellulose...	6	1	20	1,690	17,000	4,000	4
	Nitrocellulose...	5.37	1.5	45	1,830	35,000	15,000	35
	Nitrocellulose...	5.37	1.5	45	1,830	35,000	15,000	35
	Nitrocellulose...	25	1.5	55	1,000	23,000	10,000	15
	Nitrocellulose...	4.6	1.5	105	1,100	28,000	15,000	40
	Nitrocellulose...	4	1	105	1,100	28,000	15,000	40
	Nitrocellulose...	2	1	125	900	20,000	15,000	35
	Nitrocellulose...				710			
SEACOAST RIFLES AND MORTARS.	Nitrocellulose...	2.5	*½	1.057	2,100	25,000	2,000	2
	Nitrocellulose...	7	*½	18	750	18,000	5,000	5
	Nitroglycerine...	1.25	*.25	6	2,400	34,000	5,000	10
	Nitroglycerine...	1.25	*.25	6	2,400	34,000	5,000	10
	Nitroglycerine...	1.25	*.25	6	2,400	34,000	5,000	10
	Nitroglycerine...	5	*1	15	2,600	34,000	15,000	40
	Nitroglycerine...	5	*1	15	2,600	34,000	15,000	40
	Nitroglycerine...							

STANDARD DATA OF POWDERS FOR U. S. ARMY CANNON.—Continued.

Guns.	Powder.			Weight of Projectile.	Muzzle-velocity.	Maximum Pressure.	Weight of Dot.	Weight of Ballistic Sample.
	Kind.	Approximate Weight of Charge, Including Igniter.	Weight of Igniter.					
		Lbs.	Oz.	Lbs.	Oz.	Lbs.	Lbs.	Lbs.
SEACOAST RIFLES AND MORTARS— <i>Continued.</i>								
4-inch rifle, Driggs-Schroeder.	Nitrocellulose	7.5		33		34,000	15,000	60
4.72-inch rifle, Armstrong, 40 cali- bers.	Nitrocellulose	7.5		45		34,000	15,000	60
4.72-inch rifle, Armstrong, 45 cali- bers.	Nitrocellulose	10.5		45		34,000	15,000	85
4.72-inch rifle, Armstrong, 50 cali- bers.	Nitrocellulose	10.5		45		34,000	15,000	85
5-inch rifle, model 1897.	Nitrocellulose	16.5		58		38,000	25,000	125
5-inch rifle, model 1900.	Nitrocellulose	26		58		38,000	25,000	200
6-inch rifle, Armstrong, 45 cali- bers.	Nitrocellulose	19		106		34,000	25,000	160
6-inch rifle, model 1897, Mr.	Nitrocellulose	29.75		106		38,000	30,000	225
6-inch rifle, model 1900.	Nitrocellulose	43		106		38,000	35,000	350
6-inch rifle, model 1903.	Nitrocellulose	43		106		38,000	35,000	350
8-inch rifle, model 1893, Mr.	Nitrocellulose	80	1.5	317		38,000	60,000	600
10-inch rifle, model 1898, Mr.	Nitrocellulose	155		604		38,000	76,000	1,200
10-inch rifle, model 1895.	Nitrocellulose	155		604		38,000	76,000	1,200
10-inch rifle, model 1900.	Nitrocellulose	245		604		38,000	76,000	1,200
10-inch mortar, model 1890.	Nitrocellulose	34	1	575		38,000	75,000	1,800
10-inch rifle, model 1898, Mr.	Nitrocellulose	275	7.125	1,046		38,000	75,000	1,800
12-inch rifle, model 1895.	Nitrocellulose	275	7.125	1,046		38,000	75,000	2,100
12-inch rifle, model 1900.	Nitrocellulose	375	9	1,046		38,000	75,000	2,100
12-inch mortar, C. I., model 1886.	Nitrocellulose	\$34.25	1.25	824		27,500	40,000	3,000
12-inch mortar, steel, model 1880- 90, Mr.	Nitrocellulose	\$34.25	1.25	824		27,500	40,000	400
12-inch mortar, steel, model 1890, Mr.	Nitrocellulose	62		824		35,000	40,000	400
13-inch rifle, model 1895.	Nitrocellulose	660	16.5	2,400		38,000	\$75,000	6,200

* At one end; 110-grain percussion-primer at other.

† From 50,000 pounds to weight given.

‡ This charge is not to be exceeded.

When the measured velocities and pressures for uniform conditions of loading are plotted to scale, as a function of the charge, the resulting curves must be reasonably smooth.

(b) *For Powder Failing in the Physical Test.*—Determine the charge to give a pressure approximately 15 per cent greater than the service pressure for the caliber in the table.

Fire at least four rounds with this charge; if the variation in the muzzle-velocity exceeds ± 1 per cent of the mean velocity of all of the shots considered, or the variation in the pressure exceeds ± 5 per cent of the mean pressure of the same shots, three charges of identical weight will be fired to give approximately the service velocity and pressure. If the variation from the mean velocity and pressure for these rounds exceeds the variations stated above the powder will not be accepted.

(c) For calibers less than that of the 15-pounder, the above-mentioned allowed variations will be increased 25 per cent.

(d) The result must show that the powder will give the prescribed velocity within the maximum pressure stated in the table. The powder charges giving the above velocities will be approximately those stated in the table.

(e) In the tests under (a), (b), and (c) the curve of pressures, plotted to scale as a function of varying charges, must indicate no critical point in the pressure curve, as evidenced by erratic and abnormal pressures.

MANUFACTURE, INSPECTION, AND TEST.

1. *Raw Materials.*

The powder must be an ether-alcohol colloid of nitrocellulose made from bleached cotton cellulose obtained by bleaching unspun cotton-waste and thoroughly washing to remove the bleaching materials and lime salts, containing not more than 0.7 per cent extractive matter and not more than 1.25 per cent of ash. It must be of uniform character, clean and free from such lumps as will interfere with thorough and uniform nitra-

tion. It should contain only a trace of lime salts from the bleaching and no hypochlorites.

Acids.—A mixture of sulphuric and nitric acids containing no metallic salts other than salts of iron and only a trace of chlorine compounds.

Ether.—Ethyl ether containing no impurities except small quantities of water and ethyl alcohol, to be clear and colorless with characteristic pure odor. It should have less than 0.006 per cent of acidity calculated as acetic acid, a specific gravity of 0.717 to 0.723 at 20° C., and less than 0.002 per cent residue after evaporation and drying at 100° C.

Alcohol.—Ethyl alcohol of 92.3 per cent, absolute, by weight, clear and colorless, having the characteristic pure odor, having less than 0.006 per cent residue after evaporation and drying at 100° C. It should have less than 0.006 per cent of acidity calculated as acetic acid. It should be subjected to the silver-nitrate test, as follows: 3 gm. silver nitrate, 3 gm. sodium hydroxide, 20 gm. ammonium hydroxide, made up to 100 c.c. Ten c.c. of the sample diluted with 10 c.c. of water are placed in a tight bottle, to which is added 1 c.c. of silver nitrate. Allow this to stand 1 hour in the dark and examine for unreduced silver salts in clear solution after filtering. If such are found, the alcohol contains less than the allowable amount of aldehyde.

Graphite.—If graphite is used on the surface of the grains, it should be dry, ground very fine, and contain not more than a trace of silicates or compounds of sulphur, and should be free from sulphur and acids.

Carbonate of Sodium.—Should be the best quality of refined carbonate of sodium, free from sulphides. It should contain at least 96 per cent of pure NaCO_3 , calculated on a dry sample.

No substances not mentioned in these specifications may be introduced at any stage of the manufacture.

2. Nitrocellulose.

In order to properly purify the nitrocellulose, it shall be treated for at least the times specified and in the following manner:

(a) *Steaming or Boiling*.—Before pulping the nitrocellulose shall be placed in a vat and thoroughly saturated with water. The excess of water shall then be drawn off, and steam, at a pressure not exceeding 5 pounds, shall be introduced so that it will permeate the whole mass of nitrocellulose. Should the manufacturer so desire, the nitrocellulose may be boiled instead of steamed, as heretofore prescribed. The steaming or boiling shall be continued until methyl-orange and phenolphthalein show the nitrocellulose to be free from acid and alkali.

(b) *Pulping*.—When the steaming or boiling is completed the nitrocellulose shall then be pulped in fresh water, in which may be added just enough sodium carbonate solution to preserve a slight alkaline reaction to phenolphthalein in solution. During the pulping the water shall be changed as often as may be necessary to remove all impurities. The process to continue until the material is thoroughly and evenly pulped to a satisfactory degree of fineness, without lumps, and shows a clean break when a handful of it is squeezed and broken in two parts.

(c) *Poaching*.—After pulping, the nitrocellulose shall be run to the poacher, settled, and the supernatant water decanted. The pulped nitrocellulose shall then be boiled for 6 hours in fresh water, and during this time a total of not more than 7 gallons of sodium carbonate solution (one pound of sodium carbonate to each gallon of water) may be added to each 2000 pounds of nitrocellulose (dry weight).

During this boiling and during all subsequent boilings in the poacher the pulp shall be thoroughly agitated by mechanical stirrers.

After each boiling the pulp will be allowed to settle, the clear upper water will be drawn off and replaced by clear, fresh water.

After the first 6-hour boiling there shall be five other separate boilings, as follows: one for 2 hours and four for 1 hour each, making a total of 12 hours boiling and 5 changes of water.

No sodium carbonate shall be used in any boiling, except the first.

(d) *Washing*.—After the six separate boilings just described, the pulped nitrocellulose shall be subjected to ten separate washings in cold water, each washing to consist of agitation by mechanical stirrers for one-half hour in a sufficient amount of fresh water, allowing the pulp then to settle, and decanting the clear supernatant water. At least 40 per cent of the total contents of the poacher shall be drawn off after each washing and replaced by clean fresh water for the next washing. During the last washing in cold water, while the pulp is in thorough agitation, a sample will be taken for the stability and nitrogen-content tests. Should the sample fall below the requirements in the heat-tests, the poacher lot must be boiled again for five hours with two changes of water, without the use of sodium carbonate or other alkaline substance, and thereafter it must be given ten separate washings in cold water, as described for the regular treatment.

(e) *Dehydrating*.—After being properly purified the nitrocellulose must be dehydrated by alcohol. During this operation the weight of alcohol used must be at least equal to the dry weight of the nitrocellulose.

No alcohol which has been used in this operation shall be again used for this purpose, or as a solvent, until it has been rectified up to the requirements given above for alcohol.

(f) *Colloiding*.—In colloiding, the blocks of dehydrated nitrocellulose shall be broken up and the necessary amount of standard ether added. This amount is determined by climatic conditions, number of operations after colloiding, and the caliber of the gun for which the powder is intended. The amount of ether must not be less than 64 per cent of the solvent used in colloiding. The colloiding should be continued until the ether is uniformly distributed throughout the mass, the material is

free from lumps, and the whole constitutes a smooth, even colloid.

The colloided material shall be strained for the removal of lumps before going to the die-press.

(g) *Test-samples*.—The test-samples of nitrocellulose shall be selected as follows:

The nitrocellulose contained in the vessel in which the final purifying is done shall be regarded as the unit. A 4-ounce sample will be taken from each unit and kept separate from other nitrocelluloses. When a sufficient number of these unit-samples have accumulated to represent about 10,000 pounds of nitrocellulose, equal portions of each unit-sample sufficient to aggregate 8 ounces will be taken and thoroughly blended. This blend shall be marked "Blend No. —, 190—," with date when colloided and date of contract. This sample, after being submitted to the inspector for record, will be shipped to the Proving Ground, for test. The original unit-samples must be retained until report on the analysis of the blend has been received.

The inspector may also at any time require, in addition to the samples referred to above, 4-ounce samples of nitrocellulose to be taken from the vessels in which the final purifying is done, and properly labelled for shipment for test. Nitrocellulose represented by any of these 4-ounce samples, failing to pass the stability- or heat-test, will be again subjected to the boiling and washing prescribed herein after pulping, after which a second sample will be submitted. Nitrocellulose represented by such samples which fails to pass the required tests will not be colloided.

(h) *Graining and Drying*.—The colloid will be passed through dies with such uniformity as will produce the standard grain required. The area of the screen holes of the die must be at least $1\frac{1}{2}$ times the area of the cross-section of the die. After graining, the powder will be dried at a temperature not exceeding 110° F., until the amount of solvent is within that allowed for new powders, as determined by standard curves for volatiles.

Stability- or Heat-tests.—Each sample will be subjected to each of the three heat-tests: the potassium-iodide-starch, the German 135° C., and the Ordnance 115° C. tests.

Finished Nitrocellulose.—The nitrocellulose in finished powder should contain 12.60 per cent of nitrogen ± 0.1 per cent, with the understanding that this may be obtained by blending nitrocelluloses with a nitration between 12.45 and 12.75 per cent of nitrogen. But each of these should be tested separately and should satisfy the conditions prescribed for stability and solubility of nitrocellulose. It should have a solubility of 95 per cent at 15.5° C. in two parts of ether to one part of alcohol by volume; it should contain less than 0.4 per cent of organic material insoluble in acetone; after ignition it should leave less than 0.6 per cent of ash; it should give a heat-test with potassium-iodide-starch paper of at least 35 minutes; it should give a German 135° C. test of at least 30 minutes; it should contain no alkali, mercuric chloride, or other substance which will mark the heat-test in any way; it should be uniformly colloided, free from lumps, strings, or material of such consistency as to affect proper colloidizing in the colloid mixer.

Moisture and Volatile Matter.—A one-gram sample of nitrocellulose is dissolved in about 150 c.c. of ether-alcohol mixture, and 20 c.c. to 30 c.c. of distilled water added, precipitating the nitrocellulose. The liquid is evaporated leaving the precipitate, the latter is dried and weighed. The total weight of sample (one gram) less the weight of precipitate gives the weight of volatiles.

Soluble Nitrocellulose.—It must be not less than 95 per cent soluble. One gram of the finely divided dry sample is treated in a covered beaker or other suitable vessel, with 350 c.c. of a mixture of pure ethyl alcohol and pure ethyl ether, the specific gravity of the mixture to be from 0.748 to 0.750 at 20° C., with frequent stirring. The vessel is kept covered to prevent loss by evaporation. The residue is allowed to settle and the supernatant liquid siphoned off.

The extraction with ether-alcohol solution is repeated twice; the insoluble residue is poured into a tared Gooch crucible having a thin asbestos filter, and well washed with ether-alcohol. The residue is then partially dried at 80° C., and the drying completed by exposure to a temperature of 100° C., till the weight is constant. The per cent of insoluble matter subtracted from 100 gives per cent of soluble nitrocellulose, which must be at least 95 per cent. (If "soluble nitrocellulose" is to be determined in a nitrocellulose containing considerably less than 95 per cent the determination is made on $\frac{1}{2}$ gram or less.)

Insoluble Nitrocellulose.—The insoluble nitrocellulose is determined by soaking one gram of the dry sample in 125 c.c. of alcohol overnight in a covered beaker. In the morning 250 c.c. of ether is added. The sample is frequently stirred in the liquid during several hours. The residue is then allowed to settle and the supernatant liquid siphoned off. The insoluble residue is poured into a tared Gooch crucible containing a thin layer of asbestos. It is thoroughly washed with ether alcohol, dried at 100° C., and weighed. The increase of weight represents the insoluble organic matter and insoluble nitrocellulose. The total amount of insolubles must not exceed 5 per cent.

When the amount of insoluble nitrocellulose and organic residue are very small, comparative volumetric readings may be made in long tubes, allowing the insoluble material to settle after the regular treatment for solution. The lower portions of the tubes should not be greater than $\frac{1}{2}$ inch in diameter, they should be cylindrical in shape and graduated by direct weighing of residue.

Ash.—It must not contain more than 1 per cent of ash. One gram of dry sample is weighed into a platinum crucible, moistened with 2 or 3 c.c. of pure concentrated nitric acid, and cautiously evaporated to dryness on a water-bath. The residue is incinerated at full red heat, cooled, and weighed.

Alkalies.—If not more than 1.0 c.c. of decinormal acid be neutralized, the nitrocellulose will be considered free from

added alkalies. Weigh out 5 grams of nitrocellulose, add 200 c.c. of distilled water, digest at a gentle heat, with frequent stirring for thirty minutes, and boil for about ten minutes. Add a few drops of phenolphthalein solution; a pink coloration indicates the presence of water-soluble alkali. Add 10 c.c. of decinormal acid and boil for ten minutes. Filter and wash well with distilled water, then titrate with decinormal alkali.

The difference between the number of c.c. of $\frac{N}{10}$ acid added and the number of c.c. of $\frac{N}{10}$ alkali required to restore neutrality represents the alkalies (plus other substances capable of neutralizing acid) present. In addition to alkalies present, this may represent iron oxide, alumina, lime, magnesia, etc., present in the water used, or otherwise accidentally introduced as impurities during the process of manufacture.

The presence of soluble alkali would be clearly indicated. If a small quantity of insoluble alkali is indicated by the neutralization of any acid, this may be due to impurities introduced in the wash-water or in the manufacture.

Nitrogen.—It must contain 12.65 ± 0.05^1 per cent of nitrogen. A sample dried for one and one-half hours at 100°C . will be tested in a standard nitrometer by the usual methods.

The per-cent content of nitrogen is determined by analysis of a one gram sample of nitrocellulose, dried 1.5 hours at 95° to 100°C ., or in a vacuum dryer after thorough air-drying. The sample is washed into a Du Pont nitrometer by 20 c.c. of sulphuric acid. The per cent of nitrogen is read by comparison of gas given off with a standard volume. The nitrometer is standardized by preparation of a calculated standard volume of dry air at 760 mm. pressure at 20°C . in a comparison tube.

¹ Recently it has been proposed that the nitrogen content in any single sample shall be between 12.55 per cent and 12.75 per cent, and in the finished blended powder between 12.60 per cent and 12.70 per cent.

The utmost cleanliness will be observed in the manufacture. Machinery, tools, and appliances will be kept in condition necessary to prevent the incorporation of any impurities in the materials used in the manufacture.

3. *Finished Powder.*

(a) Powder for calibers down to and including 3 inches shall be dried until the residual solvent is not less than 3 nor greater than 5 per cent. At no time shall the temperature of the dry-house be allowed to exceed 109° F. This shall be determined by maximum thermometers which shall be placed in each dry-house at or near the point where the heated air is delivered into the dry-house. There must be one such thermometer at each of these points of delivery. Readings of these thermometers must be made at intervals of not less than eight hours; the maximum reading for this period must be recorded in a book kept for that purpose.

(b) It must be a uniform ether-alcohol colloid of standard quality, free from lumps, strings, uncolloided material, cracks, air-cavities, and blisters.

(c) The form of the grain shall be cylindrical; each grain shall have seven perforations parallel to the axis of the grain, one of these being through the center, the other six at the vertices of a hexagon, so placed as to make the outer and inner web thicknesses equal within the limits prescribed in the accompanying table. The grains must be free from dust, smooth, and of standard toughness. They shall be smoothly cut at the ends; all excessively long grains, slivers, butt ends, cracked, distorted, spotted, and imperfect grains must be carefully removed.

To obtain uniformity in ballistic results, the dimensions of the grains should be as uniform as possible, and the perforations should be symmetrically placed in the grains. In 20 grains selected at random and measured the

maximum and mean variations should not exceed those noted below:

Dimension.	Maximum Variation, per cent of Mean.		Mean Variation, per cent of Mean.	
	Permitted.	Desired.	Permitted.	Desired.
<i>L</i>	6.0	3.0	2.5	1.0
<i>D</i>	4.0	2.0	1.5	0.5
<i>d</i>	25.0	10.0	10.0	2.5

L = length of grain.

D = outside diameter of grain.

d = diameter of perforations.

D should be about 10 times *d*, and *L* should be about 2.25 times *D*.

Six measurements of the outside web thicknesses and of the inside web thicknesses will be made from the six outside holes for each of the 20 grains, and the 120 measurements averaged to obtain mean outside and inside web dimensions. The difference between these should not exceed 0.01 inch. For these measurements the grain should be faced true, and the burrs removed from the edges of the perforations by carefully inserting a wire from the end opposite the burr.

The dimensions of the powder grains will be determined when necessary by firing samples made up for that purpose.

(d) Powder for the 6-pounder and smaller caliber guns will be delivered graphited, the surface of the grains being covered with dry, finely ground graphite.

Graphite for this purpose must not contain more than a trace of silicates or compounds of sulphur, and must be free of sulphur and acids.

A sample of the graphite to be used will be taken as often as, in the opinion of the inspector, is necessary to insure compliance with these specifications and shipped for test.

Taking Samples.—After a lot of powder is blended and packed, ten samples are selected by the inspector from different

boxes. For large caliber powders (above 5 inches) each sample should fill a 16-ounce glass-stoppered bottle; for small caliber powders, an 8-ounce bottle.

In testing a blend is made of equal portions of all ten samples, and this blended sample is used in making all the tests required except the heat-test. For this latter, each sample is subjected to each of the standard tests.

For ballistic tests an additional sample is taken adequate to the purpose.

Stability Tests.—All powders are subjected to the standard heat-tests for stability.

Moisture and Volatile Matter, Soluble Nitrocellulose, and Insoluble Nitrocellulose.—The sample is prepared by cutting it into slices 0.02 inch or less in thickness (best done on a lathe or scraped with sharp edge of broken glass). A one-gram sample is dissolved in ether-alcohol, the insolubles precipitated by water, and the total volatiles determined as explained for nitrocellulose.

Ash.—This is determined by decomposition with nitric acid, ignition and weighing as described under nitrocellulose.

Residual Solvent.—A sample of from 5 to 20 whole grains of powder is dried in a vacuum dryer at 50° to 60° C. for two hours, cooled in a desiccator, and the loss of weight determined by weighing. This loss is considered as moisture, and the difference between this and the total volatiles, as given by the water-precipitation method, will be considered the *residual* solvents.

Nitrogen.—The prepared and dried sample is treated as described under nitrocellulose, with the same requirements.

Physical Test.—Take not less than twenty grains, representing an average of the grains in the lot of powder to be examined, and cut off both ends of each grain at right angles to the length of the grain until $\frac{\text{length}}{\text{diameter}} = 1$. Compress these slowly between parallel surfaces (screw-press, for example) until the first crack appears. The decrease in length necessary to crack the grain is calculated to per cent of original length; no grains must

show less than 35 per cent. In case of failure in this test twenty more grains are similarly tested. If the average compression of the total thirty grains is below 35 per cent the powder will be rejected. Grains of abnormal shape or having flaws will not be used in this test.

VIII.

STORAGE OF EXPLOSIVES.

Magazines.—Wide variety of practice exists among the different countries in building magazines. In Austria-Hungary light wooden structures are provided for explosives, so that the debris, in case of explosion, would be projected short distances. The English laws in reference to explosives are most elaborate and rigid; the details of magazines, the character of explosives permitted for sale and the conditions of storage and transportation are carefully prescribed therein. These stringent regulations, taken in connection with those equally stringent in reference to the manufacture and tests of all explosives, make an accidental explosion of explosives in transit or storage an exceedingly rare occurrence in England.

Explosions may result from lightning or from incendiarism; to guard against such contingencies the buildings in which explosives are stored should be well protected by lightning-conductors and be made fire-proof. Some constructions have been made in which the roof and sides are of corrugated sheet iron; the roof-trusses of iron resting on brick piers; the floor of asphalt free of grit.

All doors should be double with a vestibule between; they should be strong, fire-proof, and have strong, treble-bolt locks.

According to Guttman, the best method of protecting explosives from lightning is to build the magazine entirely of metal, extending the sides down to moist soil or connecting them well with it in several places.

A method suggested by Professor Oliver Lodge is considered efficient. This consists in covering the building completely with strong, durable iron wire netting, or running large size iron wires along all ridges and edges, with groups of wires radiating from each corner, the whole system being connected well with moist earth.

All storage-magazines should have protecting mounds or traverses of earth thrown up around them when located near other buildings or property exposed to destruction in case of explosion. When this is not possible, near-by buildings may be protected by planting thickly a deep row of trees about the magazine. As a rule, 200 yards may be regarded as a reasonably safe distance from a large storage-magazine.

Storage-magazines should not be placed within closed works if it is possible to avoid doing so.

Not more than 400 tons of black or brown gunpowder or 100 tons of nitrocellulose gunpowder should be stored in one magazine.

The English regulations prescribe that magazines for the storage of nitro-powders or high explosives shall be made of as light a form of construction as possible, compatible with sufficient strength for stability, resistance to weather, and protection against unlawful entry. The material used must not be of an inflammable nature. The temperature of magazines should be maintained at about 70° F.; if it is permitted to rise above 100° F. for any length of time the composition and stability of nitrocellulose powders may be affected; if it rises above 122° F. (50° C.), even for a few minutes, explosives stored therein should be examined for stability.

Service-magazines in coast forts are so placed as to be protected from projectiles of all kinds. The conditions as to temperature and ventilation prescribed for storage-magazines should obtain for service-magazines.

In so far as possible no iron fixtures, tools, or appliances should be used inside of a magazine.

Magazines may be heated by steam at a pressure not exceed-

ing 15 lbs. per square inch, or by hot water; the heating pipes may be of iron, but should be placed well above the floor, not lower than 6 feet 6 inches. They need not be galvanized nor otherwise coated, nor boxed in with wood; but they should be detached and not less than 6 inches from any woodwork. They should be frequently wiped clean of all dust.

All doors and windows should be made to open outwards. They should be covered with copper sheeting. All fixtures and nails should be of copper.

Following, in a general way, the English regulations, explosives may be classified, for purposes of storage, into "Groups" and "Divisions," as follows:—

Group I. Stored in Magazines.

Explosives which must be placed *in a magazine*, each division of the group requiring a separate compartment in which "magazine conditions" must be observed, except that divisions *a* and *e* may be placed in the same compartment, and *c*, *d*, and *e* need not be under magazine conditions.

Divisions.

- a.* Nitrocellulose gunpowder and black and brown gunpowder, in bulk or made up in cartridges for large-caliber guns.
Quick match.
- b.* Dry guncotton.
Dynamite.
Explosive gelatin.
- c.* Wet guncotton.
- d.* Picric acid and its derivatives.
- d.* Rapid-fire fixed ammunition for guns of 3-inch caliber and less.
- e.* Rapid-fire ammunition for the guns above 3-inch caliber, when the powder is in metallic cases, or in metal-lined boxes.

Group II.

Explosives which must be stored in a separate chamber of a magazine, or in a separate storeroom or building.

Divisions.

a. Percussion-caps.

Small-arm ammunition.

Priming and pyrotechnic composition; any composition in bulk containing either mercury fulminate or a chlorate.

Empty capped metallic cases.

Fuses (time, percussion, or combination).

Slow match.

Port fires.

Rockets.

Primers of all kinds (friction, percussion, or electric).

b. Mines, loaded.

c. Shells, filled and fused.

Shells, filled but not fused.

d. Detonating-caps.

All gunpowders, dry guncotton, dynamite, and explosive gelatin should always be kept *in magazines*, and magazine conditions strictly enforced.

Explosives in Group II should not be placed in the body of magazines, but in storerooms or chambers apart, and need not necessarily be under magazine conditions.

Divisions *c*, *d*, *e*, Group I, may be stored in magazines or as prescribed for Group II, whichever is most convenient.

No two divisions in either group should be placed in the same compartment or pile, except *a* and *e*, Group I, may be stored in the same magazine, and fuses and primers, Group II, may be kept in the shell-room of a service-magazine, but a box or cupboard should be provided to contain them only, and separately.

A magazine or storeroom for explosives may be divided into many compartments under the same roof for the different

divisions of a group, provided they are separated by substantial brick or other walls, without openings of any kind between compartments.

Explosives of the same division may be stored in the same compartment, room, or magazine.

Nitroglycerine, dynamite, explosive gelatin, and nitrocellulose may decompose above 122° F. (50° C), and magazines containing them should *never* have a higher temperature. Nitro-powders and dry guncotton should not be exposed to a higher temperature than 104° F. (40° C) for any length of time, or repeatedly for short times.

All explosives, whether stored in magazines or in storerooms, should be kept under the following conditions:

Lighting of fires near by should be strictly prohibited.

No one should be permitted to enter rooms containing explosives stored in bulk with matches in the pockets or about the person.

Oiled rags or waste, or any substance liable to spontaneous combustion, should not be kept in or near rooms containing explosives.

Floors and platforms should be kept scrupulously clean.

Benches, shelves, and all fittings and fixtures inside of storerooms or magazines should be kept free of grit and dust.

Magazines containing gunpowder of any kind, in bulk or in cartridges for large-caliber guns, nitroglycerine, dynamite, explosive gelatin, or dry guncotton should be kept under the following conditions, in addition to those which are given above:

No one should be permitted to pass through the outer door of the building except those duly employed therein, or except in the presence of the officer or non-commissioned officer in whose charge the explosives are placed, and the latter should be responsible that all regulations for safety are strictly observed. To this end,

the officer or non-commissioned officer in charge should cause all persons to observe the following regulations as to clothing:

The contents of all pockets will be examined at the outer door to see that no matches or other easily combustible substances are taken within.

As soon as the outer door is entered all coats will be removed, and iron or steel articles removed from trousers' pockets. The shoes will be carefully wiped on a mat placed just inside the outer door, and magazine rubber overshoes placed on the feet of each person.

When powder is to be examined in a magazine, a paulin, carefully dusted and shaken, should be spread out on the floor, and when the work is completed the paulin should be carefully folded so as to contain within its folds all powder-dust that may have been formed; it then should be carried from the magazine and the dust shaken into water.

Door-mats should be shaken outside the outer door after each party leaves the magazine.

Packages containing explosives in Group I should not be opened in a magazine or storeroom containing other explosives of that group. They may be opened in an anteroom or outside.

Inventory lists, showing the contents of the magazine or storeroom, should be posted and kept entered to date.

Keys of magazines and storerooms containing explosives should be carefully tagged and kept in the personal possession of the officer in charge of the explosives.

When explosives are received the original packages should be carefully examined externally, the condition of the package noted to see if it has on its surfaces any nails, grit, or other objectionable substance, and, if there be any such, it will be carefully removed. If the package is broken or defective it will be set aside to be opened and have its contents examined. All marks on each separate package will be carefully entered in the receipt record book.

Shelves should be arranged in an anteroom to receive "sample bottles." On these shelves should be kept a sample of each "lot" of nitro-explosives received and in store in the magazine. These bottles should be inspected and the contents tested from time to time.

In stacking original packages they should be so placed as to exhibit the markings.

When original packages have been emptied, the markings should be scraped off before they are sent from the magazine or storeroom.

If packages are used for explosives a second time they should be carefully examined to see that all former markings are obliterated, and that they are strong and free from dust, dirt, and foreign substances of all kinds.

In the magazine and storerooms, packages should be stacked in tiers, the same divisions being kept together, and in each division each lot separate. A clear, free aisle should be left about each lot, and in each tier the bottom layer should be separated from the floor by 1-inch battens, and each layer from the one below by 1-inch battens. In each layer an inch space will be left between adjacent packages.

Filled cartridges will be stacked separately from powder in bulk, the lots being carefully separated and each lot together.

When rooms or buildings other than magazines are used for the storage of explosives they should be thoroughly repaired, washed, dried, swept, and cleared of all movable articles before the explosives are introduced.

If there be no anteroom or vestibule in connection with a room used for the storage of explosives one should be improvised. If it is not practicable to observe the strict regulations prescribed for permanent magazines, it is possible always to require that no matches or other easily combustible substance should be taken within the building or room, and that the feet should be carefully wiped inside the outer door.

Ventilation of Magazines.

It is very important that magazines containing gunpowder should be carefully ventilated. If powder be stored in damp magazines in cases not hermetically sealed, the powder absorbs moisture and its ballistic value is thereby reduced.

With smokeless powders the temperature of the magazine has also a special influence on the muzzle-velocity. It has been found by trial that powders tested in summer and used in target-practice in winter give velocities lower than the test velocity, and those tested in winter and used in summer give higher velocities. Corrections allowing for difference of temperature of powder in firing have been ascertained and tabulated.

Powders should be tested ballistically at a standard temperature, say 70° F., and the temperatures of service-magazines should be such as to permit the powder to be delivered to the guns at as near this temperature as possible. If this is not done a temperature correction must be introduced in applying range tables.

The humidity and temperature of the air in magazines are, therefore, a matter that must be carefully watched.

It is especially important with all nitro-explosives that there should be free circulation of air, so that in case any incipient decomposition should occur, at any spot in any package, the fumes would be directly carried off, thereby preventing an accumulation of pressure and temperature, and also favoring detection of the decomposition by the odor of the escaping gases.

The air inside of magazines should be kept always above its dew-point to avoid condensation. The problem is, therefore, to keep the air circulating and to maintain it at a temperature above its dew-point. Three methods are practised to accomplish this:

1. The air of magazines may be kept above the dew-point by providing that it pass over heated steam- or hot-water pipes, using a fan or natural circulation.

2. Air-shafts with revolving hoods, like those of ships, may be arranged to face the wind and conduct a large volume of air through all rooms and galleries. It is found that a shaft about 20 inches in diameter with a well-flared hood will work efficiently in wind above 5 miles per hour. With little wind and on damp days the shafts are closed. The principle applied in this type is that the volume of air passing through must be sufficient to give its temperature to the surfaces of the rooms and galleries.

3. Some magazines are not provided with circulating air, but the air is renewed as often as possible by opening all doors and windows to the outside air whenever the conditions of temperature and dew-point are such as to make the air let in a drying air.

That is, it is necessary to establish a proper dew-point inside by heat or otherwise, and to cause a constant circulation of air by blowers, or to make use intermittingly of the natural weather conditions as they may warrant.

The regulation of the air within a magazine by natural ventilation is effected by means of thermometers inside of magazines and wet- and dry-bulb hygrometers outside. The wet- and dry-bulb hygrometers are permanently placed outside the magazine, protected from the direct and reflected rays of the sun, and from wind and rain. Magazines should be arranged with a window, and the inside thermometers should be placed at this window, so that the inside temperature may be read without opening the magazine. Before installing the inside thermometer and the outside hygrometer, the former and the dry-bulb thermometer of the latter should be compared as to their readings under the same conditions. If a difference of reading is noted, this should be entered as a correction on both instruments and applied in all computations.

The scale of the dry-bulb thermometer of the hygrometer will give the temperature of the outside air; the reading of the

wet-bulb thermometer will always be below that of the dry bulb, and the amount of this difference is the argument with which the humidity tables are entered, as explained below.

In using the wet- and dry-bulb hygrometer care must be exercised to have the well of the wet-bulb thermometer always supplied with clean, pure water, and to see that the cloth leading to the wet bulb is wet before taking any reading.

Readings should be taken in the morning and in the afternoon. These readings and the readings of the inside thermometers should be entered in a record book.

The dampness of magazines results from two causes:

1. The *condensation* of moisture from the air of the magazine on the walls, ceiling, floors, and all surfaces in the magazine. Outside air at a given temperature and relative humidity admitted to a magazine at a lower temperature may, by simply having its temperature lowered, become supersaturated and deposit moisture by condensation.

2. *Percolation* of water through the ceiling and walls often causes dampness. This is sometimes seen in magazines, especially when Rosendale cement has been used in the construction, and when sheet lead or asphaltum has not been placed over the ceilings. Such water, running into the magazine, collects in small pools and tends to keep the air constantly saturated.

After magazines have been opened the greatest care should be exercised to see that they are closed tightly as soon as the conditions favorable to opening cease to exist, or before this limit is reached.

Subject to the above conditions, magazines should be opened as often and for as long a time as possible, and every means used to get a good circulation of air.

Two tables, A and B, are provided for guidance of the person in charge of the magazine. Copies of these tables should be attached to boards hung up in each magazine. Table A gives the weight of water-vapor per cubic foot of air for each degree

from 13° to 100° F., when the reading of the wet bulb is from 0 to 14 degrees lower than that of the dry bulb. The table is not carried below one grain of water-vapor per cubic foot of air, as this is a condition seldom met with, and no harm would be done in ventilating a magazine at any temperature likely to occur with air so dry as this. Table B gives the temperature which must be shown by the inside thermometer corresponding to the weight of water-vapor per cubic foot, before the magazine should be opened for ventilation. The table gives two columns of temperature: column I gives the temperature for the magazine at or above which ventilation would be advantageous, namely, that at which the water-vapor that is in the air outside would cause a degree of humidity of 70 per cent or less inside; column II gives the low limit of temperature for the magazine below which it should never be opened for ventilation, as its degree of humidity would become 85 per cent or more, and if it is necessary to open the doors for any purpose, they should be closed again as quickly as possible.

Method of Reading the Tables.—To work these tables the readings of the wet- and dry-bulb thermometers are taken, and from Table A the weight of water-vapor per cubic foot of air is ascertained. The temperature is then taken from Table B, which is opposite that weight in the first column.

Application of Tables.—Should the thermometer in the magazine read at or above the temperature taken from column I, Table B, the magazine may safely and advantageously be opened for ventilation. If this condition is not fulfilled for a month, the first opportunity should be taken for ventilating the magazine when the thermometer in it reads between the temperatures taken from columns I and II for the weight of water-vapor per cubic foot of air at the time; but the temperature taken from column II is the minimum for the thermometer in the magazine for any ventilation to be attempted.

Length of Time to be Opened.—It must be borne in mind that conditions favorable for ventilation may not last long, especially when the temperature inside the magazine is below that outside,

TABLE A.
WEIGHT (IN GRAINS) OF WATER-VAPOR IN ONE CUBIC FOOT OF AIR FOR USE WITH TABLE B, WHEN THE READING OF THE WET BULB IS BELOW THAT OF THE DRY BULB, AS FOLLOWS:

Difference Between Dry and Wet Bulbs.															
Dry Bulb (Fahrenheit).	0°	1°	2°	3°	4°	5°	6°	7°	8°	9°	10°	11°	12°	13°	14°
110°	18.9	19.8	18.0	17.2	16.3	15.5	14.8	14.1	13.4	12.7	12.1	11.5	10.9	10.4	9.9
99	19.3	18.4	17.5	16.7	15.9	15.1	14.4	13.7	13.0	12.3	11.7	11.1	10.5	10.0	9.5
98	18.7	17.8	17.0	16.2	15.4	14.6	13.9	13.2	12.6	12.0	11.4	10.8	10.2	9.7	9.2
97	18.2	17.3	16.5	15.7	14.9	14.2	13.5	12.8	12.2	11.6	11.0	10.4	9.9	9.4	8.9
96	17.7	16.8	16.0	15.3	14.5	13.8	13.1	12.4	11.8	11.2	10.7	10.1	9.6	9.1	8.6
95	17.2	16.3	15.5	14.8	14.1	13.4	12.7	12.1	11.5	10.9	10.3	9.8	9.3	8.8	8.3
94	16.7	15.9	15.1	14.4	13.7	13.0	12.3	11.7	11.1	10.5	10.0	9.5	9.0	8.5	8.0
93	16.2	15.4	14.7	14.0	13.3	12.6	11.9	11.3	10.7	10.2	9.6	9.1	8.7	8.2	7.8
92	15.7	14.9	14.2	13.5	12.9	12.2	11.6	11.0	10.4	9.9	9.3	8.8	8.3	7.9	7.5
91	15.3	14.5	13.8	13.1	12.5	11.8	11.2	10.6	10.1	9.5	9.0	8.5	8.1	7.7	7.2
90	14.8	14.1	13.4	12.7	12.1	11.4	10.8	10.3	9.7	9.2	8.7	8.3	7.8	7.4	7.0
89	14.4	13.7	13.0	12.3	11.7	11.1	10.5	10.0	9.4	8.9	8.4	8.0	7.5	7.1	6.7
88	14.0	13.3	12.6	12.0	11.4	10.8	10.2	9.6	9.1	8.6	8.1	7.7	7.3	6.9	6.5
87	13.6	12.9	12.2	11.6	11.0	10.4	9.8	9.3	8.8	8.3	7.9	7.4	7.0	6.6	6.3
86	13.2	12.5	11.8	11.2	10.8	10.1	9.5	9.0	8.5	8.1	7.6	7.2	6.8	6.4	6.1
85	12.8	12.1	11.5	10.9	10.3	9.7	9.2	8.7	8.3	7.8	7.4	7.0	6.6	6.2	5.9
84	12.4	11.7	11.1	10.5	10.0	9.4	8.9	8.5	8.0	7.5	7.1	6.7	6.3	6.0	5.6
83	12.0	11.4	10.8	10.2	9.7	9.1	8.6	8.2	7.7	7.3	6.9	6.5	6.1	5.8	5.4
82	11.7	11.1	10.5	9.9	9.4	8.9	8.4	7.9	7.5	7.1	6.7	6.3	5.9	5.6	5.2
81	11.3	10.7	10.1	9.5	9.1	8.6	8.1	7.6	7.2	6.8	6.4	6.0	5.7	5.4	5.1

TABLE A—Continued.

Dry Bulb (Fahrenheit).	Difference Between Dry and Wet Bulbs.														
	0°	1°	2°	3°	4°	5°	6°	7°	8°	9°	10°	11°	12°	13°	14°
80°	11.0	10.4	9.8	9.3	8.8	8.3	7.8	7.4	7.0	6.6	6.2	5.8	5.5	5.2	4.9
79	10.6	10.1	9.5	9.0	8.5	8.0	7.6	7.2	6.8	6.4	6.0	5.6	5.3	5.0	4.7
78	10.3	9.8	9.2	8.7	8.2	7.8	7.3	6.9	6.5	6.2	5.8	5.5	5.1	4.8	4.5
77	10.0	9.5	8.9	8.4	8.0	7.5	7.1	6.7	6.3	5.9	5.6	5.3	4.9	4.6	4.3
76	9.7	9.2	8.6	8.2	7.7	7.2	6.8	6.4	6.1	5.7	5.4	5.1	4.8	4.5	4.2
75	9.4	8.9	8.4	7.9	7.4	7.0	6.6	6.2	5.8	5.5	5.2	4.9	4.6	4.3	4.0
74	9.1	8.6	8.1	7.6	7.2	6.8	6.4	6.0	5.6	5.3	5.0	4.7	4.4	4.1	3.7
73	8.8	8.3	7.8	7.4	7.0	6.6	6.2	5.8	5.4	5.1	4.8	4.5	4.2	4.0	3.7
72	8.5	8.0	7.6	7.1	6.7	6.3	5.9	5.6	5.3	5.0	4.7	4.4	4.1	3.8	3.6
71	8.3	7.8	7.3	6.9	6.5	6.1	5.7	5.4	5.1	4.7	4.4	4.2	3.9	3.7	3.4
70	8.0	7.5	7.1	6.7	6.3	5.9	5.5	5.2	4.9	4.6	4.3	4.0	3.8	3.5	3.3
69	7.8	7.3	6.9	6.5	6.1	5.7	5.3	5.0	4.7	4.4	4.1	3.9	3.6	3.4	3.2
68	7.5	7.1	6.6	6.2	5.8	5.5	5.2	4.8	4.5	4.2	4.0	3.7	3.5	3.2	3.0
67	7.3	6.8	6.4	6.0	5.6	5.3	5.0	4.7	4.4	4.1	3.8	3.6	3.3	3.1	2.9
66	7.1	6.6	6.2	5.8	5.5	5.1	4.8	4.5	4.2	3.9	3.7	3.4	3.2	3.0	2.8
65	6.8	6.4	6.0	5.6	5.3	4.9	4.6	4.3	4.0	3.8	3.5	3.3	3.1	2.9	2.7
64	6.6	6.2	5.8	5.4	5.1	4.8	4.5	4.2	3.9	3.6	3.4	3.2	3.0	2.8	2.6
63	6.4	6.0	5.6	5.2	4.9	4.6	4.3	4.0	3.7	3.5	3.3	3.0	2.8	2.6	2.4
62	6.2	5.8	5.4	5.1	4.7	4.4	4.1	3.9	3.6	3.4	3.1	2.9	2.7	2.5	2.4
61	6.0	5.6	5.2	4.9	4.6	4.3	4.0	3.7	3.5	3.2	3.0	2.8	2.6	2.4	2.3

60	5.8	5.4	5.1	4.7	4.4	4.1	3.8	3.6	3.3	3.1	2.9	2.7	2.5	2.3	2.2
59	5.6	5.2	4.9	4.6	4.3	4.0	3.7	3.5	3.2	3.0	2.8	2.6	2.4	2.2	2.1
58	5.4	5.0	4.7	4.4	4.1	3.8	3.6	3.3	3.1	2.9	2.7	2.5	2.3	2.1	2.0
57	5.2	4.8	4.5	4.2	3.9	3.7	3.4	3.2	3.0	2.7	2.5	2.3	2.1	2.0	1.9
56	5.0	4.7	4.4	4.1	3.8	3.5	3.3	3.1	2.8	2.6	2.4	2.2	2.1	1.9	1.8
55	4.8	4.5	4.2	3.9	3.7	3.4	3.1	2.9	2.7	2.5	2.3	2.1	2.0	1.8	1.7
54	4.7	4.4	4.1	3.8	3.5	3.3	3.0	2.8	2.6	2.4	2.2	2.1	1.9	1.7	1.6
53	4.5	4.2	3.9	3.6	3.4	3.1	2.9	2.7	2.5	2.3	2.1	2.0	1.8	1.7	1.5
52	4.4	4.1	3.8	3.5	3.3	3.0	2.8	2.6	2.4	2.2	2.0	1.9	1.7	1.6	1.4
51	4.2	3.9	3.6	3.4	3.1	2.9	2.7	2.5	2.3	2.1	1.9	1.8	1.6	1.5	1.4
50	4.1	3.8	3.5	3.3	3.0	2.8	2.6	2.4	2.2	2.0	1.8	1.7	1.5	1.4	1.3
49	4.0	3.7	3.4	3.1	2.9	2.7	2.5	2.3	2.1	1.9	1.8	1.6	1.5	1.3	1.2
48	3.8	3.5	3.3	3.0	2.8	2.6	2.4	2.2	2.0	1.8	1.7	1.5	1.4	1.3	1.2
47	3.7	3.4	3.2	2.9	2.7	2.5	2.3	2.1	1.9	1.7	1.6	1.5	1.3	1.2	1.1
46	3.6	3.3	3.1	2.8	2.6	2.4	2.2	2.0	1.8	1.7	1.5	1.4	1.3	1.1	1.0
45	3.4	3.1	2.9	2.7	2.5	2.3	2.1	1.9	1.7	1.6	1.4	1.3	1.2	1.1	1.0
44	3.3	3.0	2.8	2.6	2.4	2.2	2.0	1.8	1.7	1.5	1.4	1.2	1.1	1.0	
43	3.2	2.9	2.7	2.5	2.3	2.1	1.9	1.7	1.6	1.4	1.3	1.2	1.1	1.0	
42	3.1	2.8	2.6	2.4	2.2	2.0	1.8	1.7	1.5	1.4	1.2	1.1	1.0		
41	3.0	2.7	2.5	2.3	2.1	1.9	1.7	1.6	1.4	1.3	1.2	1.0			
40	2.9	2.6	2.4	2.2	2.0	1.8	1.6	1.5	1.4	1.2	1.1	1.0			
39	2.8	2.5	2.3	2.1	1.9	1.7	1.6	1.4	1.3	1.2	1.0				
38	2.7	2.4	2.2	2.0	1.8	1.7	1.5	1.3	1.2	1.1	1.0				
37	2.6	2.3	2.1	1.9	1.7	1.6	1.4	1.3	1.1	1.0					
36	2.5	2.2	2.0	1.8	1.7	1.5	1.3	1.2	1.1						
35	2.4	2.1	1.9	1.7	1.6	1.4	1.2	1.1	1.0						
34	2.3	2.0	1.8	1.6	1.4	1.2	1.1	1.0							
33	2.2	2.0	1.7	1.5	1.3	1.1	1.0								
32	2.1	1.9	1.6	1.4	1.2	1.0									
31	2.1	1.8	1.5	1.3	1.1	1.0									

TABLE A—Continued.

Dry Bulb. (Fahrenheit).	Difference Between Dry and Wet Bulbs.														
	0°	1°	2°	3°	4°	5°	6°	7°	8°	9°	10°	11°	12°	13°	14°
30°	2.0	1.7	1.4	1.1	1.0										
29	1.9	1.6	1.3	1.0											
28	1.8	1.5	1.2												
27	1.7	1.4	1.1												
26	1.7	1.3	1.0												
25	1.6	1.2													
24	1.5	1.1													
23	1.5	1.1													
22	1.4	1.0													
21	1.4	1.0													
20	1.3														
19	1.3														
18	1.2														
17	1.1														
16	1.1														
15	1.1														
14	1.0														
13	1.0														

TABLE B.

SHOWING TEMPERATURE AT WHICH MAGAZINES MAY BE OPENED FOR VENTILATION, ACCORDING TO THE MOISTURE IN THE OUTSIDE AIR ASCERTAINED FROM TABLE A.

Weight of Water-vapor in One Cubic Foot of Air (Outside) Ascertained from Table A.	Temperature of Magazine When It May be Opened.		Weight of Water-vapor in One Cubic Foot of Air (Outside) Ascertained from Table A.	Temperature of Magazine When it May be Opened.	
	I.—Minimum for Good Ventilation.	II.—Limit below which Ventilation is Injurious.		I.—Minimum for Good Ventilation.	II.—Limit below which Ventilation is Injurious.
Grains. ¹	Degrees F.	Degrees F.	Grains. ¹	Degrees F.	Degrees F.
17.0	107	100	5.2	68	62
16.5	106	99	5.0	67	61
16.0	105	98	4.9	66	60
15.5	104	97	4.7	65	59
15.0	103	96	4.6	64	58
14.6	102	95	4.4	63	57
14.2	101	94	4.3	62	56
13.8	100	93	4.1	61	55
13.5	99	92	4.0	60	54
13.1	98	91	3.8	59	53
12.7	97	90	3.7	58	52
12.3	96	89	3.5	57	51
12.0	95	88	3.4	56	50
11.6	94	87	3.3	55	49
11.2	93	86	3.2	54	48
10.9	92	85	3.1	53	47
10.5	91	84	3.0	52	46
10.2	90	83	2.9	51	45
9.9	89	82	2.8	49	44
9.6	88	81	2.7	48	43
9.3	87	80	2.6	47	42
9.0	86	79	2.5	46	41
8.8	85	78	2.4	45	40
8.5	84	77	2.3	44	39
8.2	83	76	2.2	43	38
8.0	82	75	2.1	41	37
7.7	80	74	2.0	40	36
7.4	79	73	1.9	39	35
7.2	78	72	1.8	38	34
7.0	77	71	1.7	37	33
6.8	76	70	1.6	35	32
6.6	75	69	1.5	33	31
6.3	74	68	1.4	31	30
6.1	73	67	1.3	29	28
5.9	72	66	1.2	27	26
5.7	71	65	1.1	25	24
5.6	70	64	1.0	23	21
5.4	69	63			

¹ When the number of grains of water-vapor per cubic foot of air is not found exactly in the column, the nearest higher figure should be taken.

as the latter will soon fall after entering the magazine when the doors are opened, and the relative humidity of the outside air which has entered the magazine be increased. Under these circumstances about five minutes should be long enough for ventilating a small magazine; but when the temperature inside is above that outside the magazine and other conditions are fulfilled, there is no limit to the time during which ventilation may be continued, provided outside conditions remain favorable.

Lighting.

Magazines of permanent seacoast works are lighted, as a rule, by electricity. When lighted by lamps, or when it is necessary to take a lamp into a magazine or a room containing explosives, only some authorized type should be used.

Great care must be exercised in protecting electric lamps from being broken, and the insulation of all parts of electric circuits within the magazine, or the room containing explosives should be of the most approved form.

It has been ascertained by experiment that the incandescent filament of the electric light will fire gunpowder dust if the globe be broken in an atmosphere containing such dust in suspension. It is considered necessary, therefore, to have all incandescent lamps protected by a strong outer glass globe and this latter by a strong, copper-wire cage; the outer glass globe should have an inlet and outlet tube admitting a circulation of air; the capacity of the globe and ventilating pipes should be such as to keep the temperature inside the outer globe not greater than 140° F.

In the case of very dusty and dangerous localities, the outer globe may be arranged to contain water instead of air, and a circulation of water provided, the lamp being immersed therein. In all cases where complete globes are used, one side should be painted to prevent the focussing of heat rays.

Lamps should be attached in such a manner as to make it

impossible to be broken by a fall; for this purpose a light wire cage is placed immediately about the lamp globe. No wire carrying a current should be used to *support* a lamp, or be otherwise subjected to a mechanical stress.

Lead wires should be inclosed in metal tubing up to the lamps, and the lamp wires should be soldered to the leads. No mere contact-joints should exist in the leads within or near the magazine. Each lamp should be provided with a fuse cut-out outside the magazine, so placed as to be readily inspected. The fuses should consist of tin wire about 0.036 inch in diameter, additional wires in parallel being used if necessary.

Each lamp should be supplied with a double-throw switch outside the magazine, by means of which the circuit may be completely broken. Before attempting to repair or replace a lamp, this switch should be thrown off for that lamp.

An efficient leakage-detector and lightning-arrester should be placed in each magazine-lighting system.

The difference of potential between any parts of the circuit within magazines should not be greater than 110 volts.

The system should be thoroughly tested from time to time in all its parts.

Special Storage Regulations for High Explosives.

High explosives in storage should have blue litmus strips placed in each package. These packages should be examined once a month, the litmus strip replaced, and the boxes turned over.

The floor under packages containing nitroglycerine explosives should be covered with clean sawdust, to absorb any nitroglycerine that might exude. This sawdust should be renewed from time to time, the old sawdust being burned in the open air.

In case a floor, or package, becomes coated or stained with free nitroglycerine, the latter should be decomposed by washing the floor or package with a solution of flowers of sulphur in

carbonate of sodium. This soda-sulphur solution should be kept on hand wherever nitroglycerine in any form is stored.

Dynamite should be stored so that the sticks are horizontal; the tendency of dynamite to exude nitroglycerine is greater if the sticks stand on end.

It is important that dynamite-cartridges be kept dry. If exposed to a moist atmosphere, there is a tendency of the water condensed from the air on all exposed surfaces to displace the nitroglycerine.

A little sodium carbonate is usually placed in dynamite. Moisture often causes this to leave to some extent the body of the cartridge and to appear as a white efflorescence on the outside of the wrapper. If the dynamite is not otherwise changed, particularly if blue litmus is not reddened and there is no leaking of nitroglycerine, the efflorescence does not in itself indicate deterioration. It does suggest, however, that an examination of the dynamite should be made with a view to determining its condition as to the other defects named.

Guncotton is always stored in a saturated condition, containing from 30 to 35 per cent of water. In this condition it is practically non-explosive. If not stored in hermetically sealed cases, guncotton should be examined monthly and resaturated.

Dry guncotton is required as a primer in detonating wet guncotton. Dry guncotton primers should be stored apart from wet guncotton. The disks may be kept dry by immersing in melted paraffin. If dry primers so prepared are not on hand, wet disks should be dried out at temperature not above 110° F.

Liquid nitroglycerine is very rarely kept in storage. If it becomes necessary to store it, it should be stored in earthen crocks only, and should be kept covered with water. These crocks should be placed on supports of wood, near the floor, and over a trough containing sawdust or other absorbent. Like dynamite and guncotton, it should be examined monthly with blue litmus for evidences of acidity.

All buildings and rooms containing these explosives should

have a free circulation of air and should be under other magazine conditions.

Examination of Smokeless Powder in Magazines.

A sample of each accepted lot of powder is kept at the works of the manufacturers, where it is observed from time to time and tested. A part of each sample should be kept exposed at about 104° F. (40° C.), under conditions resembling as near as possible those which obtain in storage-magazines. This part of the sample should be carefully examined from time to time, and subjected to the stability test once every three months for the period of one year and thereafter, as long as any of the lot is in the service, once every six months. A small part of the original sample should be kept permanently in a glass bottle, in a suitable place, where it can be under observation. Another sample of each lot of the powder should be placed in a glass-stoppered bottle, with a piece of moistened litmus paper suspended just clear of the powder. This should be kept in position for six hours, moistening the litmus paper from time to time, noting whether the litmus paper reddens and to what extent, and being careful not to confuse the pink color due to the ordinary bleaching of litmus with the reddening due to free acid. In order to determine what the *acid color* for a given piece of litmus should be, a piece of the paper should be dipped in vinegar and the true acid color will result. If this color develops in the bottle, it is due to escaping nitro fumes.

Care should be taken to prevent the direct rays of the sun from falling upon powder or powder-boxes.

External Examination.

In making superficial examinations of smokeless powder a small scoopful should be taken into a good light, where a change of color may be most readily detected. Decomposing powder becomes lighter in color all over or in spots, showing a decidedly

yellow tinge, and, when the decomposition is well established, the grains become in a measure soft, yielding to the pressure of the thumb nail. If nitro fumes are given off, the inside of the box, tank, or bag would probably show a yellowish appearance, and an acrid, pungent odor of nitric-oxide gas would be present. Close observation is necessary to detect these signs in the case of incipient decomposition, but, if discovered at any time, such powder should at once be subjected to the stability heat-test.

If any powder is found to be in a soft or pasty condition, it should be removed at once and put in water.

Samples of each lot of powder received at a magazine should be kept in glass-stoppered bottles and so placed in the magazine that they can be regularly and carefully examined twice a day.

When a shipment of powder is received at a storage-magazine, each box or package which shows signs of rough handling and liability that its hermetical sealing has been destroyed should be opened and a superficial examination made of its contents to ascertain if it is in normal condition.

Fixed ammunition received for storage should have a few rounds taken apart for superficial examination.

Heat- and litmus-tests should be made in each case where superficial indications of incipient decomposition are observed, and unless the powder meets both of these tests it should not be placed in the magazine.

In preparing fixed ammunition, care must be exercised to see that the inside of the case is free from grease or any other foreign substance, and that the base of the projectile is perfectly clean.

The temperature and hygroscopic conditions of magazines should be constantly watched. Maximum and minimum thermometers should be placed one in the hottest part of the magazine and the other in the coolest. The temperatures should be taken daily and noted in the Magazine Record Book.

Magazines should be inspected each day and the fact noted in the Record Book over the signature of the person who makes the inspection.

At these inspections the general condition of the magazine and its contents should be examined and noted in the Record Book. If the condition of the magazine is such as to indicate that everything is in a satisfactory state the word "Normal" should be entered. If otherwise, the particular defects noted should be spread upon the Record, and the matter reported at once to the proper officer.

No loose powder should be permitted in any building, except such as is actually being used in preparing cartridges.

Large quantities of powder should not be permitted in cartridge-filling rooms; only just enough to supply the immediate need.

As rapidly as cartridges are filled and prepared for use, they should be removed from the filling-rooms and placed in storage.

Neatness and cleanliness should be insisted upon at all times; no foreign substances, such as oakum, waste, rags, paper, paint-pots, -brushes, etc., should be allowed in any building assigned for the storage or preparation of cartridges.

If it should at any time become necessary to dry smokeless powder, it should be done out of the direct rays of the sun.

Smokeless powder should not be stored in magazines wherein the temperature runs at any season above 95° F., or which ever reaches 104° F. If the temperature tends to rise so high artificial cooling must be resorted to.

If the odor of ether is noticeably strong in any magazine, such magazine should be blown out with portable fans or otherwise ventilated.

A naked light should never, under any circumstances, be taken into a room containing any quantity of powder.

The following tests and examinations should be made of smokeless powders kept in service-magazines at posts:¹

¹ These tests do not apply when powder is stored in soldered metallic cases.

Daily.—A sample from each lot of smokeless powder in the magazine is to be kept in a glass-stoppered bottle¹ in a conspicuous place, and frequently examined in a good light as to its external appearance.

Fortnightly.—The powder in one or more boxes or bags of each lot to be examined externally for evidences of incipient decomposition.

Monthly.—The sample in the index-bottles will be subjected monthly to a moist litmus-paper test for 30 minutes.

Quarterly.—A sample from each lot in the magazine to be subjected to the potassium-iodide-starch-test for 40 minutes once a quarter, and also to a six-hour litmus-test.

In case a pungent odor is detected it should be investigated.

The following regulations, with regard to the care and preservation of smokeless powders in store, are prescribed by the Ordnance Department, U. S. Army:

All lots of smokeless powder will, as far as practicable, be shipped from the manufacturers to one of the powder depots; except, under unusual circumstances, issues to posts will be made only from such depots.

In issuing smokeless powder from the depots the oldest lots in store will be issued first, unless instructions to the contrary be given.

All powders stored at the powder depots shall be tested as follows:

1. By the usual stability tests at the Ordnance Laboratory. For this purpose an 8-ounce sample from each lot of powder in store will be sent to the laboratory for test.

These tests of powder shall be made each six months after delivery. The samples will be selected as follows: From lots for the 10-inch and 12-inch B. L. rifles not more than one grain shall be taken from a box; from lots for guns of other

¹ The style of bottle desired is that known as "salt-mouthed" bottles and of a capacity of about two pounds; they should be filled about two-thirds full.

calibers 5 per cent of the boxes shall be opened and a proportionate part taken from each.

2. A litmus paper test will be made every three months for six hours from a sample taken from one or more boxes of each lot. The sample is placed in a clean glass-stoppered bottle, and a piece of litmus paper moistened with water (distilled, if practicable) is suspended just clear of the powder.¹

3. In each magazine samples of each lot stored therein should be placed in glass-stoppered bottles and examined semi-weekly. The appearance of yellowish or brownish-red fumes gradually assuming a red color as the quantity increases is a sign of deterioration. The fumes have a disagreeable, sharp, acrid odor similar to that of nitric acid, and are very irritating to the eyes and nose.

Should there be any indication of fumes the bottle should be opened and two pieces of litmus paper moistened with water (distilled water, if possible) quickly inserted, one in contact with the powder and one hanging from the stopper. If there are any fumes being evolved, the litmus paper should be reddened in a few hours. The moist paper will gradually dry out; if any doubts exist as to its reddening, the paper should be again moistened and replaced. The papers should be exposed in the bottles or boxes for at least six hours.

4. Small samples of each lot should be kept in glass bottles, either in the offices or in some suitable place for purposes of daily observation. These bottles should not be exposed to the direct rays of the sun, nor in any place where they would be liable to be overheated.

¹ The caution mentioned on page 221 as to the true acid color, should be kept in mind.

IX.

HANDLING HIGH EXPLOSIVES.

WHILE the explosives herein treated have enormous potential energy stored up in them, they are perfectly safe unless a definite act be taken to let loose this energy.

If they are so handled that no particle of any given mass is brought to a certain definite temperature by application of heat, friction, or shock, they are as safe as any other solids or liquids. The solid nitro-explosives are at least no more dangerous than the old black gunpowder. The precautions to be kept in mind have been pointed out as the several explosives have been taken up in succession. Some of the more important of these may, perhaps, with advantage be collected and repeated here.

Summary of Precautions of a General Nature to be Observed in Handling Explosives.

Avoid bringing any matches or other easily combustible substances near an explosive.

Avoid the use of hard, rigid tools, implements, or apparatus in connection with explosives. A particle of explosive pinched between two hard surfaces, and subjected to a blow or to sliding friction, is apt to explode. The minutest particle caught in this way and exploded has the power to initiate the explosion of a large mass. Copper is the only metal that should be used about explosives.

Use only the quantity of explosive necessary for the work in hand, and keep the main supplies far removed from the point of explosion, and well protected from all possible exposure to fire or shock, or to handling by unauthorized persons.

Keep explosives and means of exploding them apart until it is desired to arrange a charge for explosion.

Explosives and primers, fuses or caps, should never be transported or stored together.

Nitroglycerine, dynamite, dry guncotton, and explosive gelatin, if transported, should be protected against violent shock by preparing a soft, elastic bed of hay, straw, excelsior, or similar substance in the cart, wagon, or car. Rough pavements and roads should be avoided in so far as practicable.

Never prepare a primer dynamite or explosive gelatin cartridge near other dynamite or explosive gelatin.

Never try to thaw nitroglycerine or a nitroglycerine derivative over a naked flame or on heated metal. Use always a closed vessel in a water-bath.

In case a charge at any time misses fire, *do not be in haste to investigate the cause.* Wait at least ten minutes, and, then, when satisfied that no explosion is to take place, remove the tamping, cut the lead-wires of the fuse, and prepare another primer. Open up the charge as little as possible and not near the old primer.

In using an electric current for firing, the wires should not be connected to the source of electricity until the circuit is otherwise complete, the primer in place, and charge all ready for firing. One man should be detailed to see that the firing ends of the wires are not tampered with while the charge is being arranged.

Before firing a charge, warning should be given to all persons connected with the firing, and a lookout stationed to warn off all friends.

Precautions to be Observed in Charging Torpedoes and Shell with High Explosives.

The work should be done in light frame buildings apart from other buildings. The floor must be swept frequently, and the sweepings burned at a distance.

The temperature of the loading-room should not be above 90° F. nor below 50° F.

No acids or primers should be allowed near explosives in bulk. Magazine conditions will be strictly enforced, both as to persons engaged in the work and to the surroundings.

In connecting together parts of material by screwing, as in fusing shell and arranging the torpedo fuse, great care must be exercised that no particle of explosive is caught in the screw-threads.

Shell loaded with picric acid or its derivatives should not have screw-threads coated with white or red lead.

Great care must be taken that particles of explosive are not dropped on the floor.

A torpedo loaded with dynamite should be kept carefully protected from the sun's rays. The direct rays of the sun would soon heat the interior to a high degree, and the sensitiveness of all high explosives increases rapidly with the temperature. Loaded torpedoes should, therefore, be kept in the shade, and, if necessary, covered with paulins.

Safety Precautions in Preparing to Fire Demolition Charges.

1. In testing fuses or detonators never attach a wire to either lead, unless the fuse or detonator is safely inclosed or at a safe distance.

2. Always hold a cap or primer pointing from you.

3. Be careful not to bend, strike hard, or heat a cap or primer.

4. Do not place caps or primers near strong acids.

5. Be careful not to allow any strain to be put on the leads of a primer in making up a charge or in connecting up the circuit.

6. Any one who connects a wire to the lead of a primer is responsible for his own safety. He should not make the connection unless he *knows that the circuit is broken* between him and the source of electricity. To increase safety, the outer ends of the circuit should be put in charge of some person, with instructions to keep the leads apart.

7. All persons except those directly engaged in the work should withdraw to a safe distance or take cover while the charge is being made up and the circuit prepared.

8. The exploding-machine, electric battery or other firing apparatus, should not be brought to the firing-point until all preparations for firing have been made. The *last* thing before firing is to connect the leads with the source of electricity.

9. Place the exploding apparatus or machine as near the charge as safety permits. Before using, test the machine by seeing if it will redden, by heating, a small piece of platinum wire, or if it will explode a spare primer, or take the throw of a galvanometer, or the shock of the current between ends of short leads attached.

10. If a charge is to be fired by using a firing-key, examine carefully to see that there is a *real and sufficient break* when the key is "off," and that there are no loose wires or other means near to form a circuit except through the key. In firing, connect one terminal of the firing-key with the positive pole of the firing-battery, and, lastly, connect with the battery's negative pole.

11. *Immediately after firing, disconnect both leads and place them in charge of some responsible persons, as explained in 6.*

12. In testing circuits and primers, not more than $1/20$ ampere should flow through any primer.

13. For certainty of ignition, a single large charge should have two or more primers connected up in parallel, thus:

14. Always use the same kind of primers in the same circuit.

The utmost care must be always exercised in handling all kinds of explosives and in their preparation for firing. The tendency of those charged with the duty of handling explosives is to become careless and indifferent, and to neglect those precautions and that carefulness which should always be observed in connection therewith. Only the constant, utmost

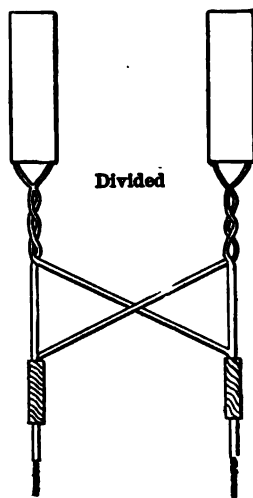


FIG. 1.

watchfulness will avoid accidents. No relaxation of these precautions or of the rules and regulations governing magazine duties should be permitted.

Preparing a Charge for Firing.

In arranging a charge for firing, the primer-cartridge of dynamite or the primer-disk of guncotton is placed as near as possible in the middle of the charge, and the mass of explosives packed tightly around it.

The charge may be ignited by a time-train fuse, or by an electric primer or cap.

If a time-train is used, its rate of burning must be ascertained by trial. A single-tape time-train fuse will burn at the rate of about 1 foot in 18 seconds, a double-tape fuse the same distance in about 20 seconds.

The time-fuse is cut to the desired length, placed in the open end of the cap, and the latter pinched down tightly on it, as shown in Fig. 2.



FIG. 2.

If the fuse is to be used under water, the cap must be well coated with paraffin, tar, or shellac, so as to make the joint water-tight.

The cap is next inserted in the cartridge. In doing this,¹ open that end which has the longest paper-folds. Punch a hole in the center of the end of the cartridge with a round-pointed stick, making the hole slightly larger than the cap. Insert the cap (about two-thirds of its length) until it is almost but not quite covered by the explosive. Bring the paper of the cartridge close around the fuse-train and tie tightly with a strong

¹ The description contemplates a dynamite stick-cartridge.

string. The primer-cartridge thus made will appear in longitudinal section, as shown in the following figure.

The charge having been arranged with the primer-cartridge as near as possible in the center, the train is led off in the direc-



FIG. 3.—Primer-cartridge arranged with time-train fuse.

tion of cover, its free end is ignited, and the operator quickly withdraws.

In firing by electricity, an electric primer is used. A primer-cartridge is prepared as follows: The paper is unfolded at one end of the cartridge, an opening is made in the center of the end with a pointed round stick, a little larger than the primer-cap. The cap is inserted until the upper end is nearly but not quite flush with the upper surface of the explosive in the cartridge. The lead-wires are then bent sharp over the end of the cartridge and along its side to the opposite end, leaving the free ends of the wires at that end. In passing along the cartridge, two half-hitches should be taken around the cartridge with the lead-wires, one near the end in which the cap is placed, to prevent the latter from being disturbed; the other near the opposite end. When completed, the primer-cartridge should appear as in Fig. 4.



FIG. 4.—Primer-cartridge arranged for electric firing.

To allow for this arrangement, and to allow also for ample free ends, the lead-wires should be at least 6 feet long.

This primer-cartridge should be placed at the center of the charge and the components of the charge packed tightly about it, the free lead-wires passing out through the charge in the direction of the point from which it is to be fired.

In the case of guncotton, a dry block is taken for the primer-

block. The primer is placed in the hole of the block and packed in tightly with scraped dry guncotton taken from the corners of the block. The leads are then bent over and around the block, making a close-fitting half-hitch. If it is to be fired under water the whole should be dipped in melted paraffin.

In jointing wires, strip off the insulation for about two inches, leaving the end of the insulation conical, like the wood part of a pointed lead-pencil, and clean the wire carefully with the back of a knife, or other suitable tool, until a smooth, even, bright metallic surface is obtained, being careful not to nick or roughen the surface of the bared wire if possible. Cross the wires at right angles, as shown in Fig. 5. Then bend each wire around the

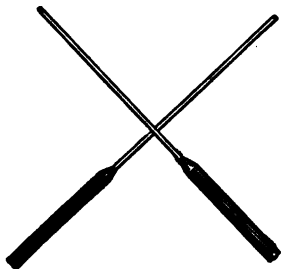


FIG. 5.

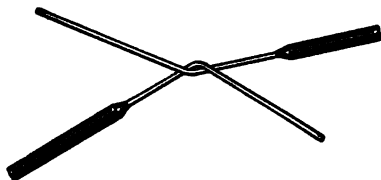


FIG. 6.

other spirally in the direction of the pointed insulation of the other wire, keeping the turns of the spiral close together, as shown in Figs. 6 and 7. Three or four turns should be made, *pressing the turns tightly down on the standing part of the other wire*, using pincers, preferably, to make the turns regular and tightly pressed on the other wire. Cut off the spare ends and pinch the cut ends close down, as shown in Fig. 8.



FIG. 7.



FIG. 8.

In jointing stranded wires, each strand should be separately cleaned, and each strand wrapped around the standing part of the other wire, as explained above for a solid wire.

A three-way joint is made by first making a simple joint, as explained above, and then opening the wires at the first crossing sufficiently to insert the bared end of the third wire, as shown in Fig. 9. This third wire is wrapped closely down

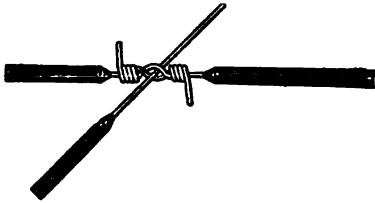


FIG. 9.

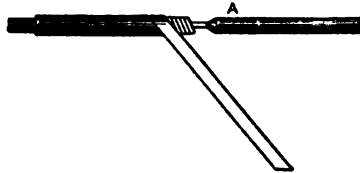


FIG. 10.

on the turns of the first wires. Other wires may be connected in, in the same manner.

Important joints should be soldered if time allows. To solder a joint, first wash the joint with zinc chloride, heat the soldering-iron until it will readily melt the solder. Rub one face of the iron with a coarse file, then rub over a little sal ammoniac; or dip it quickly in a solution of sal ammoniac, then rub the solder on this cleaned face of the iron and apply to the joint. The solder should be hot enough to run freely into the spaces between the wires. The joint is then washed clean with carbonate of soda or other alkaline solution. Instead of zinc chloride, a solution of resin in spirits of wine may be used.

Great care should be taken to keep the bare hands off the scraped wires, and to keep the latter free from all grease.

All joints, whether soldered or not, should be insulated. This is accomplished by the usual insulating rubber tape. Begin well down on the wire insulation and wrap spirally well over on the insulation of the other side of the joint; letting each turn overlap the previous one one-half, ending in a half-hitch (see Fig. 10).

If the joint is to lie under the water, each turn of the insulation-wrapping should be carefully smeared with india-rubber solution before the next turn is laid over it. In unsoldered

joints, the india-rubber solution should not be placed over tape lying next to and immediately over the twisted wires. Care must be taken to notice that the tape *adheres* to the rubber solution as it is laid down, and especially to the insulation of the wires on each side. To insure this, the insulation of the wires and the tape to be laid down should be cleaned off with a little naphtha, and the insulation smeared with rubber solution.

A good water-tight joint may be made by slipping a piece of rubber tubing on the wire before the jointing, then, after the jointing, slipping it over the joint and binding it on each side tightly down on the wire insulation with strong twine or with pliable wire.

If neither tape nor tubing is available, a fairly good insulated joint, suitable for use in damp places, may be made by slitting longitudinally the insulation of a spare piece of wire, detaching it carefully from the wire, cutting this piece in two across, and then applying the two sections over the joint and binding down tightly with twine or fine wire.

A joint should be made in that part of the circuit least liable to moving or bending. If necessary, the joints should be fixed in position by weights or stakes or staples.

Before a circuit is connected up for firing, the joints should be tested for continuity. The complete circuit should finally be tested by a weak current.

The service-exploder is known as the Laffin & Rand Magneto-electric Machine, or the Laffin & Rand Exploder.

The internal arrangement (see Figs. 11, 12, and 14) consists of a Siemens armature, *B*, which revolves between soft-iron prolongations of the cores of an electromagnet, *A*.

The electricity is generated by forcing the armature to revolve in the field of the magnet and is transformed by a commutator, *F*, from an alternating to a continuous current. The circuit passes from the commutator-springs into the adjacent ends of the windings of the magnet. The back-strap ends of the windings of the two halves of this magnet are extended to the terminals, or binding posts, *G*, for the connecting wires;

and thence to a brass spring, *D*, and collar, *E*, where, by platinum points, they are joined together, thus completing an interior short circuit as a shunt. The magnet is wrapped with 1.76 ohms of cotton-insulated copper wire, No. 18, B. W. G., and the armature with 0.92 ohms of No. 21 of the same. The novelty of the machine lies in the mode of giving rotation to the Siemens armature, and of switching into the firing circuit the powerful induced current. Both objects are accomplished by the firing-bar, which consists of a square brass

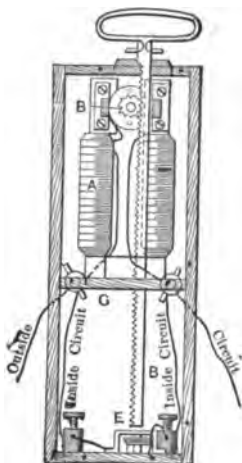


FIG. 11.—End View.

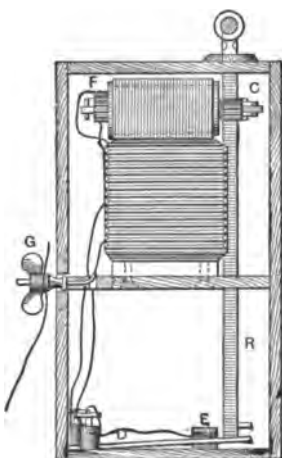


FIG. 12.—Side View.

rod, 14 by $\frac{1}{2}$ by $\frac{1}{2}$ inches, fitted with a wooden handle at one end, the other end passing down into the box. One side of the bar is provided with teeth which engage in a loose pinion, *C*, fitted over the prolongation of the armature spindle. A clutch holds the pinion to the spindle when the rod is descending, but leaves it free when the latter is raised, thus restricting the revolutions of the armature to one direction only. When the firing-bar reaches its lowest position, it strikes the brass spring which forms part of the interior circuit; and, if in rapid motion, the shock breaks the circuit and thus shunts the current into the firing circuit.

In passing from the top to the bottom of the box, the rod causes seven and one-half complete revolutions of the armature; and, if the movement be the result of a sudden and downward pressure, this is enough to develop a powerful electrical current.

This form of exploder is very compact and strong, and not liable to get out of order except through very rough usage.

The machine may become temporarily deranged through two causes:

1st. Dust or some foreign substance may find its way between the platinum contact-points between *D* and *E*, Fig. 11.

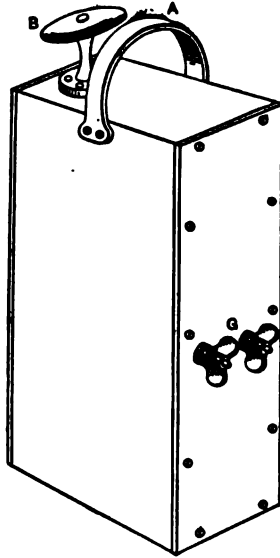


FIG. 13.

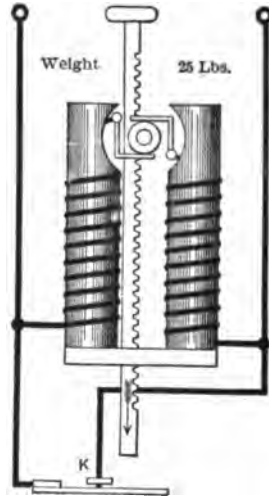


FIG. 14.

By removing the screws that hold it in place, the rear of the case may be removed and the trouble remedied by using a piece of fine emery-cloth.

2d. Trouble may arise from the surface of the commutator becoming tarnished. In order to cleanse it, remove the rear of the case as before, and also the small pin near the lower end of the firing-bar, and then withdraw the firing-bar from the case.

The works of the machine, with the shelf upon which they rest, are next partially removed from the case, and the springs which press upon the commutator, and the yoke which holds in place the spindle upon which the commutator revolves, are disconnected. The commutator may then be cleaned with a piece of fine emery-cloth.

Proper attention to these details and careful preparation of the wires and fuses save a vast deal of trouble, and cannot be too strongly insisted upon when success is absolutely necessary and time is to be saved.

To use the exploder, note that safety precautions have been taken by all persons; clean the lead ends; attach cleaned ends to the binding-posts (*G*, Fig. 13) of the exploder; raise the firing-bar¹ (*B*, Fig. 13) to its full height; force the firing-bar down with firm, rapid, uniform stroke, keeping the bar vertical.

In some recent forms of this exploder, there are three binding-posts for firing a larger number of primers than can be fired by two. The third post is connected at a central point of the group of fuses; the current goes out on this central line and divides over the two return routes. The resistance is thus lowered, so that a sufficient current is developed to fire the primers in each return route.

¹ The firing-bar should be kept down at all times, except in the act of firing.

X.

DEMOLITIONS.

DEMOLITIONS may be divided into two kinds: (1) deliberate and (2) hasty.

In the case of deliberate demolitions, time is not an important factor in the preliminary arrangements, and economy of means and material may be given due consideration.

In hasty demolitions, the saving of time is the controlling consideration. Tamping, and other means of economizing the quantity of explosive required for a given demolition, must often be neglected, and hence hasty demolitions require relative larger quantities of explosives than deliberate demolitions. Hasty demolitions only are considered in these notes.

When the demolition requires *mass effect*, a progressive explosive like gunpowder is to be preferred to a high explosive. If a local shattering effect is desired, the latter is to be preferred.

With gunpowder, tamping is essential if a good effect is to be had. Tamping is not so important with dynamite, gun-cotton, and other high explosives. The full effect of dynamite is obtained when the tamping is equal in thickness to the thickness of the mass to be destroyed; with gunpowder, the tamping should be $1\frac{1}{2}$ to 2 times thicker.

Demolitions may be "moderate," in which the fragments remain at or near the point of explosion; or "violent," in which the fragments are scattered and thrown to some distance.

In destroying masonry revetment walls, the charge should be placed on the back of the wall on a level with the foot of it,

and along the length of the wall to be demolished. For this purpose a gallery must be driven through the revetment and extended right and left behind it. The charge should be sufficient to destroy the wall, and should be covered in the gallery through the revetment with earth $1\frac{1}{2}$ times the thickness of the wall. If the wall have buttresses, there should be an additional charge and tamping opposite these points. The foot of the wall may be reached by a shaft from above, instead of a gallery through it. The lateral galleries should be run the same, however.

The resistance of ordinary masonry may be taken at $1\frac{1}{2}$ times that of a similar thickness of earth. A tamping of earth over the charge double the thickness of the wall should be sufficient.

Buildings.

Large buildings with substantial masonry walls should have the charges laid at intervals all along the ground at the foot of the outside walls. A ditch dug parallel to the line of charges will furnish earth for tamping.

If the charges be let a short distance into the wall, the charge may be smaller and the tamping reduced.

It would be better to place the charges inside, but, as a rule, the interior arrangements, floors, etc., interfere, and it is difficult to get sufficient earth for tamping.

When there is difficulty in getting earth for tamping it may be necessary to *blast* the walls down.

Blasting is effected by relatively small charges of explosives placed in holes of small diameter called "bore-holes." It is resorted to only where hard, rigid material is to be removed, such as rock, masonry, etc. The charge must be put in the form to fit the bore-holes. The stick form of dynamite is a convenient one to charge bore-holes.

The positions of bore-holes with respect to the mass to be demolished are important.

The direction of maximum effect is at right angles to the bore-hole opposite the center of the charge. The charge should be so placed that the "burden" of the charge is on this line. This line of the "burden" of the charge is the "line of resistance," abbreviated L.R. It is the longest line from the charge at right angles to the bore-hole in the direction the explosive effect must be carried.

The angle of the bore-holes should be less with the face of the mass, the harder and more tenacious the latter.

When there are two free surfaces the bore-hole should be run parallel to the longest free side, as illustrated in Fig. 16: acb = probable crater.

If the mass be vertical and have an undercut, as in Fig. 17, the bore-hole should be driven at least beyond the angle at d . The depth of the bore-hole should be at least $\frac{3}{4}$ A.D. If the side AD is not parallel to the bore-hole ac , then L.R. is the *longest* perpendicular to the charge. In all cases the size of

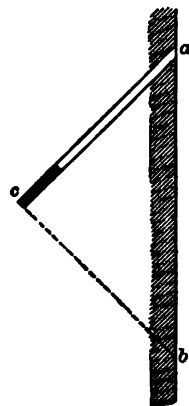


FIG. 15.

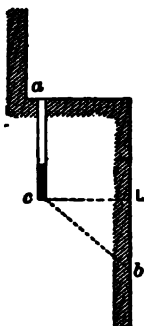


FIG. 16.

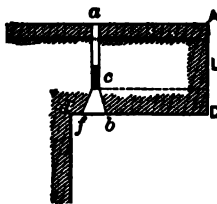


FIG. 17.

the charge must be adjusted to this longest perpendicular. If this is not done, a small crater like acb might be made, leaving the rest of the mass undisturbed.

A vertical-face undercut without a top surface should be arranged as in Fig. 18, the bore-hole being parallel to the undercut face.

When several bore-holes are placed in series the distance between them should be equal to the $1\frac{1}{2}$ when fired separately, and equal to $\frac{1}{2}$ L.R. when fired simultaneously.

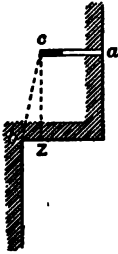


FIG. 18.

In charging a bore-hole, as many sticks of dynamite or other explosive as may be required, according to the computation for the charge, are placed in the hole, pressed firmly with a wooden drift until the sticks are in close contact with each other and with the sides of the bore-hole. The primer-cartridge is placed in last. A paper or cloth wad is placed over this, and the whole is tamped with sand or other material.

The weight of charge in ounces may be computed by the following formula:

Let C = total charge in ounces.

c = charge per foot run of bore-holes in ounces, i.e.,

$\frac{C}{\text{length of bore-hole in feet.}}$

L.R. = line of resistance in feet.

k = coefficient of resistance of the mass to be blasted.

B = length of bore-hole in feet.

Then

$$C = k(L.R.)^2,$$

$$k = \frac{C}{(L.R.)^2},$$

$$c = \frac{C}{B}.$$

k is determined by experiment for the material to be blasted. When not known, and there is not time to determine it, it may be taken as 0.2.

For blasting purposes dynamite or explosive gelatin is, as a rule, more convenient than gunpowder or guncotton.

Buildings can, as a rule, be demolished more economically and readily by blasting charges placed *in* the walls than by charges placed along the bottoms of walls and covered with earth.

Charges of black gunpowder will be effective in demolishing walls when placed at the middle of the wall, provided the charge is in compact form, and the diameter of the bore-hole is greater in inches than the wall is thick in feet.

In boring into walls, the holes should slant downward toward the middle of the wall at an angle of 45° . The middle of the wall will be reached when the bore-hole is $1\frac{1}{2}$ L.L.R.¹ The hole must then be lengthened so as to contain one-half the charge, and to bring the center of the charge at the middle of the wall.

The amount of explosive may be reduced by cutting away portions of the wall, leaving only piers to be demolished.

If the strength of the wall varies from point to point by buttresses or other construction, the charge must be increased at such points. Bore-holes may be driven as follows:

Single.—Slant downwards at 45° , alternating on opposite sides of the wall.

V-shaped.—Same, but directly opposite each other, meeting at the middle of the wall.

X-shaped.—Same, but crossing at middle of wall.

The table on page 247 gives the charges of black powder required for demolitions when placed twice the line of least resistance apart.

If the holes have to be made with a diameter in inches less than $\frac{3}{4}$ L.L.R., *V* or *X* holes may be used with diminished intervals, or two parallel holes cut side by side and the partition between them cut away.

¹ L.L.R. = line of least resistance; it is that line drawn outward from the charge along which the resistance is smallest.

Diameter of Hole in Inches.	Charge of Powder in Pounds.	Depth to which each Hole is to be Bored in Feet.	Kind of Hole.	Length of Hole Occupied by Powder in Feet.	Remarks. Charges to be Fired Simultaneously.
2 L.L.R.	$\frac{1}{2}$ (L.L.R.) ¹	1 $\frac{1}{2}$ L.L.R.	Single	$\frac{1}{2}$ L.L.R.	This is the best size of hole.
1 $\frac{1}{2}$ "	$\frac{1}{4}$ (L.L.R.) ¹	1 $\frac{1}{2}$ "	"	$\frac{1}{2}$ "	Half the charge in each hole; overlap <i>slightly</i> . Half the charge in each hole; overlap equally, forming X. L. L. R. always expressed in feet.
"	$\frac{1}{2}$ (L.L.R.) ¹	2 $\frac{1}{2}$ "	"	1 $\frac{1}{2}$ "	
"	$\frac{1}{2}$ (L.L.R.) ¹	1 $\frac{1}{4}$ "	V	$\frac{1}{2}$ "	
$\frac{3}{4}$ "	$\frac{1}{2}$ (L.L.R.) ¹	2 "	X	1 $\frac{1}{2}$ "	

Bridges.

The destruction of bridges is an important division of demolitions. Usually the time available for preparation is brief; traffic over the bridge cannot be interrupted during the preparation; and, finally, the destruction must be accomplished suddenly when the proper time has arrived, and the demolition must be certain and complete.

The proper way to destroy a masonry bridge of a single arch is to demolish one or both haunches.

A bridge having piers should have the charges placed at the bottom of the piers, and several charges should be placed rather than one large one, since the risk of failure of a single charge should not be run; several charges should be placed at 2-lined intervals.¹

The arch of a bridge offers greater resistance to destruction than a plane surface. The charge should always be placed on the haunch and so that *cb* is the L.L.R.; its resistance being less than *ca*, or any other line out from *c* to any surface.

In order to insure these relations, *ca* or any other line should be equal at least to 3 *cb*. The distance between charges across the width of the bridge should not be greater than 2 *cb*.

¹ Intervals apart equal to 2 L.L.R.

If the charge is to be destroyed with a single charge, the L.L.R. (cb) should be made equal to at least $\frac{1}{4}$ the width of the bridge. Except with very narrow bridges, it would be better to use multiple charges.

A single charge placed at the crown is not advisable, for the reason that it may simply blow out the crown, as indicated

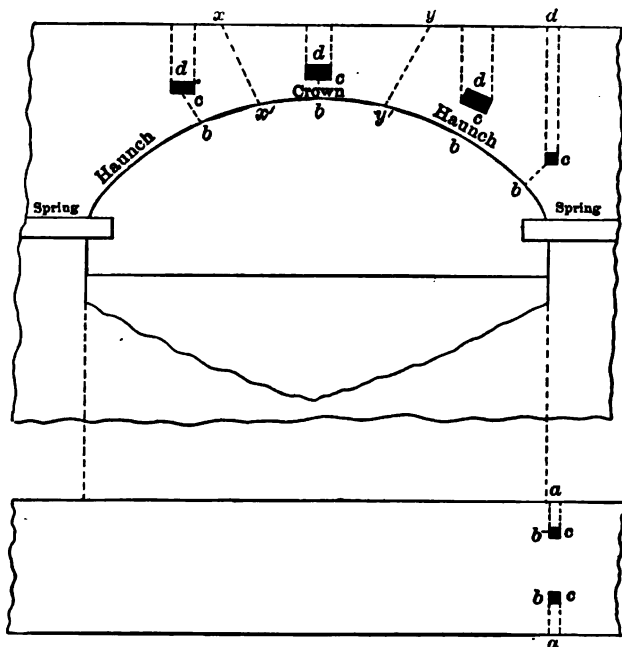


FIG. 19.

by the lines xx' and yy' , making the repair of the bridge a comparatively simple matter. It might be that this, in some special case, would be desired; then an overcharge should be distributed across the bridge along the crown, midway between the roadway and the surface of the crown.

When there is not sufficient time to place charges to destroy the haunches, several rows of charges should be placed over the arch, as shown at ddd . The distances between these charges across the width should not be greater than 2 L.L.R. The

L.L.R. should be regulated by the depth of the stones forming the arch. It should not, as a rule, be less than $1\frac{1}{2}$ feet nor more than 5 feet: if less than the former, the charges would be too small; if greater than the latter, too large.

Another method of arranging the charge is to place it in a trough suspended below the arch. This answers better for high explosives than for gunpowder.

Wooden bridges may be destroyed by explosives, cutting through the important ties or struts of the middle section, or by burning or cutting or sawing through the important members.

The following empirical formula is given by Captain H. Schaw, R.E., for determining the charge of powder required to demolish a strongly built masonry arched bridge, when the charge is well tamped and placed over the haunch, at a depth below the roadway equal to twice the distance through to the surface of the arch: $C = \frac{2}{3}(L.L.R.)^2 \times B$.

If on the arch: $C = \frac{2}{3}(L.R.R.)^2 \times B$ $\left\{ \begin{array}{l} \text{Placed in a shallow} \\ \text{trench along crown on the} \\ \text{keystone, with excavated} \\ \text{material placed over it.} \end{array} \right.$

In which C is the total charge of powder in pounds required for the charge in a single mass, or in line across the bridge; L.L.R. is the line of least resistance; B is the breadth of the bridge in feet.

When a bridge is wide, the charges may be placed, without stopping traffic, by sinking a shaft in the middle of the roadway and placing a board cover over the shaft. When the bridge is narrow, the charges may be placed by running galleries from the side walls. If the mining be difficult and the time limited, it may be necessary to resort to overcharged mines.

Iron-girder Bridges.

These bridges should, as a rule, be destroyed by demolishing the girders, their members or parts, rather than by blowing up the piers, unless there be ample time and it is desired to effect the greatest damage possible.

Girders may be solid and continuous, as in the simple I-beam girder, or they may be in the form of a built-up truss.

Where there is a continuous truss across several spans, the shore spans should be cut near the first pier, thus:

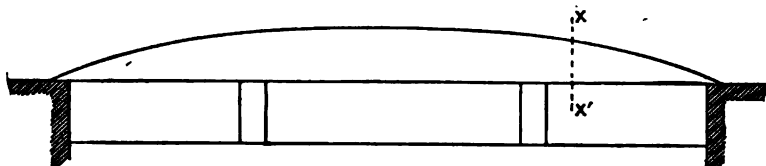


FIG. 20.

Cut at XX' . If the spans are large, usually it will be sufficient to cut one span.

When the girder is not continuous, but rests separately as a single span:

(a) If it consist of a single span of uniform cross-section throughout, as is usually the case with small bridges, cut near both ends, thus:

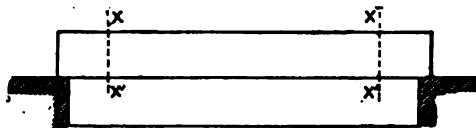


FIG. 21.

(b) If it consist of a truss, or strengthened beam, cut at a point near each support just before the first strengthening or thickening of the parts begins, thus:

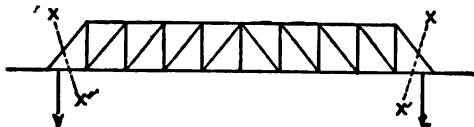


FIG. 22.

Specific rules cannot be laid down for cutting each separate

type of truss, but there are certain general rules, such as those just given, which may be taken as a guide.

To insure complete destruction, the cut should be made through the entire truss. When there is not available sufficient explosive for cutting through a whole truss, the upper and lower chords should be cut. If there is not enough for both chords, cut the *tension*-chord of the panel rather than the *compression*-chord.

With a solid I-beam girder, the explosive should be placed on both top and lower flange and against the web between.

Curved girders, whether solid or built up open, should be cut completely through on both haunches, if possible.

Suspension bridges should be cut through each cable, either at the middle of the cables or near the anchors; the former for large bridges and the latter for small ones.

Large iron-truss bridges on stone piers may be most effectually destroyed by blasting the piers, but this should be attempted only when there is ample time. Small girder-bridges may be pried by levers off their piers or abutments, if no explosives be at hand.

Iron-truss bridges may be destroyed also by fires built against the important struts or ties; when red-hot, the heated members will give way and the structure will collapse.

Suspension bridges may be destroyed by uncovering and destroying the anchorages of the supporting wires, by destroying the supporting pier below the saddle, or by cutting through the wires at the middle.

In blasting stone piers, charges should be at two-lined intervals in the middle of the pier, computing the size of the charge by the following formula:

$$C = \frac{1}{3}(L.L.R.)^3.$$

Iron Plates.

To cut iron plates, the charge must extend along the entire line to be cut. The weight of charge in pounds may be computed approximately from the following formulas:

For wrought iron or soft steel: $C = \frac{3}{4}Bt^2$.

For cast iron: $C = \frac{1}{4}Bt^2$.

B = length to be cut in feet.

t = thickness of plate in inches.

Laminated plates should be treated as solid. Care should be taken that the contact of the charge with the plate is close throughout.

Subaqueous Demolitions.

The most common subaqueous demolitions are the blowing-up of sunken hulks, cutting down piles, and removing rocks from channels.

Hulks are broken up by exploding large single charges inside of the hulk. For this purpose, it is necessary for divers to go down into the hulk to place the charge.

Guncotton is a convenient explosive for under-water demolition, as its explosive force is not diminished by being wet. It is only necessary to arrange in the charge a primer of dry guncotton.

If dynamite or powder is used, it is necessary to inclose the charge in a water-tight case. Various common articles may be found to answer for a case, such as beer-barrels, iron sewer-, gas-, or water-pipes, lead pipes, rubber tubing, fire-hose, etc.

Explosive gelatin is unaffected by water, and, like guncotton, may be detonated if a primer of the dry explosive be used.

Single piles may be cut by using an encircling charge, in the form of tubing or hose, or by a single charge held in place at the proper height. The single charge may be fastened to a long beam, and the latter used to press the charge against the pile.

If a row of piles is to be cut down, the same principle may be applied. Fasten an extended charge to a heavy plank; attach the latter to two or more beams or scantling; lower until the ends of the beam bite into the bottom; lash the upper ends of the beams to the top of the piling, pressing the charge tightly up against the piles.

The charges for subaqueous demolitions may be considered as "tamped" charges, and the weight of charges computed for piles by the same formulas as given for hard-wood trees and stockades.

Masonry Tunnels.

Either the crown of the arch or the side-walls may be attacked. To prepare crowns of arches for demolition shafts may be sunk from above or galleries run from the ends, or openings made through the wall or arch and galleries run laterally from these. The side-walls may be prepared for demolition by opening holes through the wall, and running galleries laterally, or running galleries from the ends behind the walls, as explained for masonry revetment walls.

If time is limited, the charges may be placed along the foot of each wall and tamped.

If it is desired to break-in several yards in length of the tunnel, "over-charge" charges should be placed some distance along the arch or walls behind them, reckoning the resistance equal to two or three times the thickness of earth.

The part of a tunnel selected for destruction should be, if possible, some distance from either end. Ventilating shafts may easily be destroyed, and some tunnels thereby rendered unserviceable. If the subsoil is plastic, or contains water under pressure, great damage may be done by opening a hole through the foundation.

Stockades or Barriers.

The charge should be placed along the bottom and tamped; a single row of charges of dynamite or other explosive will usually be sufficient. The strength and character of the barrier must be considered.

An ordinary stockade or barrier-gate will be broken in by the equivalent of 40 to 100 lbs. of black powder fastened near the lock. Larger and stronger fort-gates should be attacked with the equivalent of 200 lbs. of powder placed along its bottom.

Demolition of Railroads.

The destruction of railroads may be divided into three classes of operations:

1. Those looking to the rendering of a particular portion of the line unserviceable for a limited time.
2. Those looking to the total destruction of the railroad, its works and rolling-stock.
3. Hasty demolitions having in view the production of the maximum amount of damage at some point or section in a limited time.

In classes 1 and 3, it is necessary to know the time limit. A reconnaissance should precede each, so that the precise nature of the work to be done may be ascertained and the necessary tools, material, and men may be determined.

The railroad may be within the enemy's line and be in use by him, or it may be within our own lines and its destruction made advisable, in order to prevent its use by the enemy at a subsequent time. In the latter case, all rolling-stock and movable property should be collected at a safe interior point.

Buildings, storehouses, workshops, etc., need not be destroyed. The machines may be rendered useless and engines disabled, but buildings should not be destroyed; water-supplies

especially should only be subjected to injury that may be repaired later. The demolitions should include lighting and signal appliances, switches, bridges, tunnels, embankments, cuts, etc.

Apart from the removal and destruction of particular pieces of property, the simplest and quickest method is to destroy the rails by explosives. Two sticks of dynamite or one block of guncotton, fastened by wire or cord close to the web of a steel or iron rail and detonated in that position, will completely destroy that portion of the rail. A string of cartridges may be applied in this manner, one charge to each rail, placed in series and exploded at the same time, thus destroying a great length of track instantaneously.

Land-mines.

The nomenclature and essential data connected with the use of explosives in land-mines are here briefly given:

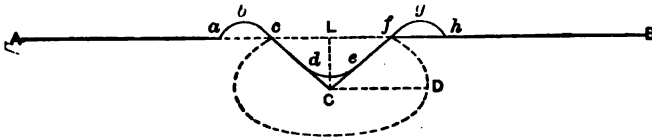


FIG. 23.

Let AB represent the original surface of the ground; C , the position of the center of the charge; CL , the line of least resistance.

After explosion, the crater will take the form $cdefgh$, with the crest, $abc-fgh$, about it.

The line cf is the diameter of the crater; Lf is the radius of the crater.

The radius of explosion is DC , the distance through the earth to which the effects of the explosion extend. When a crater is formed, the horizontal radius of explosion is greater than the vertical radius; when there is no crater, these two radii are equal. In the former case the volume included in the effects of rupture is a spheroid; in the latter case it is a sphere.

When the radius of explosion is greater than the line of least resistance, the mine is an "overcharged mine"; when less, an "undercharged mine"; when equal, a "common mine."

The following formulas give the charge of black powder, or equivalent, required to form these mine craters:

$$\text{For overcharged mine: } C = \frac{k}{10} [L.L.R. + 0.9(r - L.L.R.)]^3.$$

$$\text{For undercharged mine: } C = \frac{k}{10} [L.L.R. - 0.9(L.L.R. - r)]^3.$$

$$\text{For common mine: } C = \frac{k}{10} (L.L.R.)^3.$$

C = charge in pounds.

$L.L.R.$ = line of least resistance in feet:

r = radius of the crater in feet.

k = a constant depending on the nature of the soil. It may be given the following values:

For very light earth.....	0.8
“ common earth.....	1.
“ hard sand.....	1.25
“ earth and stones.....	1.45
“ clay.....	1.55
“ inferior brickwork.....	1.65
“ rock and good brickwork.....	2.25
“ best brickwork and masonry.....	2.50

Arrangement of Charges

The charge may be applied either concentrated in one mass, or extended in a long line. In case the object to be demolished is a piece of rectangular shape and small in dimensions, like a beam, or round like a tree or pile or mast, a modification of the latter form of charge may be used by encircling the beam or tree with the extended charge. A piece of rubber hose is a convenient means of holding the explosive.

In case a piece of hose is not available, an encircling charge may readily be arranged by distributing the explosive on a piece of canvas, or other strong cloth of suitable length and width, and the cloth rolled over so as to form a long cylinder; this should be overwrapped spirally with strong twine and lashed snugly about the object to be destroyed.

In all cases, all parts of the charge should be brought into the closest possible touch with each other, and the whole charge with the surface of the object to be demolished.

For breaching or cutting through a plane surface of any kind, the charge may be attached to a plank, the parts being lashed tightly to the plank and in close contact with each other. The whole plank may then be applied to the surface of the object to be demolished.

Such objects as trees and wooden beams may be cut conveniently by charges placed in auger-holes bored into them. The auger should be about two inches across its bit. The hole should be bored along a diameter of the tree, or perpendicular to the axis of the beam. If one hole will contain the charge, only one should be bored; if one hole is not sufficient, others should be bored, meeting at the center, or parallel to the first. The centers of charges should be at middle of the tree or beam in each hole.

TABLE OF RELATIVE STRENGTHS OF VARIOUS HIGH EXPLOSIVES.

Name of Explosive.	Order of Strength.
Explosive gelatin.	106.17
Nitroglycerine.	100.00
Guncotton.	83.12
Dynamite, No. 1.	81.31
Rackarock.	61.71
Melinite and other picric-acid explosives.	50.82
Black gunpowder in small grains.	28.13

A stick of dynamite weighs about 6.73 ozs. (190 grms.).

A disk of guncotton weighs about 10.63 oz. (300 grms.).

A stick of explosive gelatin weighs about 1.42 oz. (40 grms.).

SUMMARY OF CHARGES FOR HASTY DEMOLITIONS.

(USING DYNAMITE OR GUNCOTTON CHARGES.)

 B = length of breach to be made in feet. T = thickness of object to which charge is applied in feet. t = thickness in inches of iron plate.

These charges are for untamped conditions; if tamped, they may be reduced one-half.

When prepared in great haste in the presence of the enemy, increase the charges one-half.

Object	Lbs.	Remarks.
Hard-wood trees, round. . . .	$3 T^3$	Also piles, masts, etc., encircling charge or single charge outside.
Hard-wood beam, rectangular	$3 BT^3$	B = longer side of cross-section, encircling charge or single charge outside.
Hard-wood stockade or barrier.	$3 BT^3$	B = length of breach; T = maximum thickness of stockade; single charge.
Earth and wood stockade or barrier.	4 per foot.	This is for breastworks 2 to 3 feet thick, made of earth rammed between planks or railway sleepers.
Iron-rail stockade or barrier. .	7 per foot.	This made of iron rails touching each other, placed in ground on end.
Hard-wood tree, round. (Soft-wood objects require only one-half of the charge required by the same object in hardwood.)	$\frac{1}{2} T^3$	T = smallest diameter of tree; auger-hole charge. Hole bored radially, so that center of charge shall be at center of the tree.
Brick and masonry revetments.	$\frac{1}{2} BT^3$	Charge placed behind revetment against its back surface; for scarp-walls of forts and surfaces of tunnels.
Heavy gates.	50 lbs.	Gates of forts, armories, etc.
Iron plates, wrought or steel.	$\frac{1}{2} Bt^3$	t = thickness in inches. Laminated plates same as solid.
Detached masonry or brick wall, over 2 feet thick.	$\frac{1}{2} BT^3$	If over 2 feet thick.
Detached masonry or brick wall less than 2 feet thick.	2 per foot.	Charge calculated by last formula would be too heavy, and simply blow a hole through the wall.
Masonry piers of bridges. . . .	$\frac{1}{2} BT^3$	Placed against the pier in close contact.
Masonry arches of bridges. . .	$\frac{1}{2} BT^3$	Placed along the crown of haunches.
Field- or siege-guns or R. F. guns.	$1\frac{1}{2}$ lbs.	Placed on the chase near the muzzle.
Large seacoast guns.	4 lbs.	In bore tamped from the breech and muzzle with sand or earth.
Steel rails.	$\frac{1}{2}$ lbs.	Lashed tightly to the web of the rail.
Inflammable buildings or materials may be ignited by	1 disk of dry gun-cotton.	Disk should be simply ignited, not detonated.

Explosive gelatin would require charges 20 per cent less than those above.

Gunpowder would require charges 4 times greater than those above.

APPENDIX.

LABORATORY EXPERIMENTS.

The following simple experiments illustrate the chemical principles set forth in Principles of Chemistry, Part I:

EXPERIMENT No. 1.

To illustrate the formation of a metallic oxide, and the influence of temperature in the action of chemical affinity (paragraphs 31 and 116).

Apparatus and Materials:

1. Blowpipe.
2. Small piece of charcoal, about three inches long.
3. Gas- or lamp-flame.
4. Forceps.
5. Small piece of iron.
6. Small piece of copper.
7. Small piece of zinc.
8. Small quantity of mercury.

Preparation: Make a small depression near one end of the charcoal. Scrape clean the surface of charcoal in this depression and the surface adjacent thereto before using the blowpipe.

Procedure:

- (a) Take a small piece of iron, brighten it with a file or emery-paper, place it in the depression in the charcoal and bring to bear on it the outer point of the blowpipe-flame. The bright surface of the iron becomes dull, due to the combination of the oxygen of the air with the iron under the influence of the heat of the flame, and the formation thereon of a film of black iron oxide.
- (b) Repeat (a), using a piece of copper; its oxide is also black.
- (c) Repeat (a), using a piece of zinc; note the coating of zinc oxide

on the surface of the charcoal near the depression, which is yellow when hot and white when cold.

- (d) Repeat (a), using a small globule of metallic mercury; note the coating of mercury oxide on the charcoal, which is red.

EXPERIMENT No. 2.

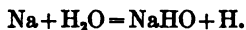
To illustrate the formation of metallic hydroxides (paragraphs 58 to 63).¹

Apparatus and Materials:

1. Small piece of metallic sodium.
2. A porcelain surface.
3. Distilled water.
4. A small glass tube for use as a dropper.
5. A small quantity of fat (unslaked) lime.
6. A porcelain bowl.
7. Solution of zinc chloride.
8. Solution of potassium hydroxide.
9. Two small beakers.

Procedure:

- (a) The formation of the hydroxides of the alkaline metals (K, Na, Li, Cs, Rb). Cut a thin slice of metallic sodium and place it on the porcelain surface. Add water carefully with a dropper. Hydrogen is liberated from the water. A slight explosion may occur. A crusty grayish residue of sodium hydroxide is left on the porcelain surface. The reaction is as follows:

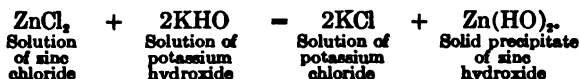


- (b) The formation of the hydroxides of the alkaline-earth metals (Ca, Ba, Sr, Mg). Place a piece of fat (unslaked) lime, about the size of a bean, in the porcelain bowl. Add water until the lime is half covered. The process of "slaking" will take place, the fat lime swelling and crumbling up and finally reducing to a fatty, pasty mass with evolution of considerable heat. The resultant pasty mass is calcium hydroxide. The reaction is as follows:



¹ See also Experiments Nos. 22, 23, and 24.

- (c) The formation of the hydroxides of metals other than the alkaline and alkaline-earth metals. Take a small quantity of the solution of potassium hydroxide in one of the beakers, and a small quantity of the solution of zinc chloride in the other beaker. Pour one solution into the other. The mixed solution now has a milky-white opaque appearance. This is caused by the production of the insoluble zinc hydroxide. This reaction also illustrates the principle of insolubility (paragraph 116). The reaction is written as follows:



EXPERIMENT No. 3.

To illustrate the formation of non-metallic oxides (paragraph 31).

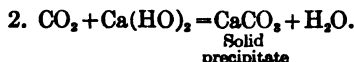
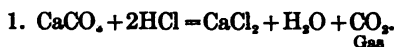
Apparatus and Materials:

1. Small quantity of calcium carbonate (marble or chalk).
2. Small quantity of hydrochloric acid.
3. Small quantity of roll sulphur.
4. Porcelain dish.
5. Small quantity of alcohol.
6. Small glass funnel.
7. Small piece of filter-paper, colored blue by having been dipped in solution of indigo.
8. Nitric acid.
9. Small piece of tin.
10. About 3 feet of rubber tubing to fit funnel above.

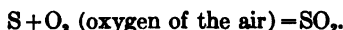
Procedure:

- (a) *Carbon dioxide.* Drop a small quantity of hydrochloric acid on the calcium carbonate. Effervescence will occur due to the escaping carbon dioxide. A piece of moistened blue litmus held in the escaping gas will be turned red, this being a test of the acidity of the escaping gas. A lighted match held in the gas is extinguished, exhibiting the power of carbon dioxide to extinguish flame. If the escaping gas is collected under the glass funnel, the rubber tube be attached to the neck of the funnel, and the gas conducted into some clear lime-water, the latter will become turbid, due to the formation of the

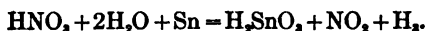
precipitate of insoluble calcium carbonate. The reactions are as follows:



(b) *Sulphur dioxide.* Take a piece of roll sulphur about the size of a bean, place it in the porcelain dish, pour a little alcohol in the dish, and ignite the latter. The sulphur will soon be ignited by the burning alcohol, and will burn with a blue flame, giving off an exceedingly pungent odor, due to the gas, sulphur dioxide, which has been formed. This gas has the property of extinguishing flame, and gives the acid test with moistened blue litmus. It also has the property of bleaching, as may be illustrated by moistening the blue filter-paper and placing it in the neck of the glass funnel while the latter is held over the burning sulphur. The reaction is as follows:



(c) *Nitrogen dioxide.* Take a small piece of tin, about $\frac{1}{4}$ " square, place it in the porcelain dish and pour on it some nitric acid. Nitrogen dioxide will be evolved as a gas; if the reaction does not readily take place, dilute the acid with water. The gas, in coming off, gives rise to reddish fumes. The odor is very pungent. The reaction is as follows:



EXPERIMENT No. 4.

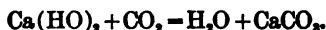
To illustrate the direct combination of an acid oxide and a basic oxide or basic hydroxide (paragraph 32).

Apparatus and Materials:

1. Small piece of lime.
2. Shallow porcelain dish.
3. Distilled water.
4. Filter-paper.
5. Small glass funnel.
6. Short piece of rubber tubing.
7. Small beaker.
8. Woulfe bottle.
9. Calcium carbonate (marble, chalk).
10. Hydrochloric acid.

Procedure:

- (a) *Acid oxide and basic oxide.* Water for this purpose may be considered an acid oxide, being the combination of a non-metal with oxygen, and lime the basic oxide. Place a small quantity of lime in the porcelain dish. Cover it half with distilled water. The phenomenon of "slaking" described in (b), Experiment No. 2, will take place. The experiment and reaction are in all respects the same as in that experiment.
- (b) *Acid oxide and basic hydroxide.* Take carbon dioxide as the acid dioxide, and calcium hydroxide as the basic hydroxide. Generate the carbon dioxide as follows: Place a small quantity in the Woulfe bottle. Attach the rubber tubing to one neck. Pour hydrochloric acid in through the other neck, then close the latter with a rubber stopper. Carbon-dioxide gas will be generated in the bottle and pass out through the rubber tubing. Conduct this into a beaker filled with lime-water (water containing calcium hydroxide—slaked lime—in solution). The clear lime-water will become turbid as soon as the carbon dioxide enters, due to the formation of insoluble calcium carbonate. The reaction is



EXPERIMENT No. 5.

To illustrate the formation of an oxyacid (paragraph 45).

Apparatus and Materials:

1. Apparatus and materials required for (b), Experiment 3.
2. Apparatus and materials required for (b), Experiment 4.
3. Glass funnel.
4. Iron-ring support for funnel.
5. Rubber tubing attached to neck of funnel.
6. Beaker.
7. Distilled water.

Procedure:

- (a) Generate SO_2 as in (b), Experiment No. 3. Support funnel with tubing attached over burning sulphur. Conduct SO_2 through tubing into distilled water in beaker. The water and SO_2 unite, forming sulphurous acid. The reaction is



- (b) Generate CO_2 as in (b), Experiment No. 4. Conduct through tubing into distilled water. A certain quantity of CO_2 will remain in the water, this quantity depending on the pressure. The resulting liquid is carbonated water. It is sometimes called carbonic acid.

EXPERIMENT No. 6.

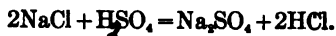
To illustrate the formation of a hydracid (paragraph 50).

Apparatus and Materials:

1. Solution of common salt in a beaker.
2. Sulphuric acid.

Procedure:

Add sulphuric acid to solution of common salt. Hydrochloric acid will escape as a gas. The reaction is



EXPERIMENT No. 7.

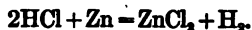
To illustrate the property of an acid to exchange its hydrogen for a metal (paragraph 52).

Apparatus and Materials:

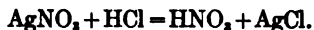
1. Metallic zinc.
2. Silver nitrate solution.
3. Hydrochloric acid.
4. Beaker.

Procedure:

- (a) Place a small quantity of HCl in the beaker. Drop in small pieces of zinc until effervescence ceases. The HCl will have been changed to ZnCl_2 . The gas escaping is hydrogen (H). The reaction is



- (b) Place a small quantity of HCl in the beaker. Add silver nitrate. The clear HCl will turn white with insoluble silver chloride formed. The liquid remaining is nitric acid. The reaction is



The silver has displaced the hydrogen in the acid, and the hydrogen has been united with NO_3 , forming nitric acid.

EXPERIMENT No. 8.

To illustrate the formation of an *ous* acid (paragraph 47).

Same as (a), Experiment No. 5.

EXPERIMENT No. 9.

To illustrate the formation of an *ic* acid (paragraph 47).

Apparatus and Materials:

1. Potassium chlorate.
2. Manganese dioxide.
3. Ignition-tube.
4. Rubber tube.
5. Beaker.
6. Sulphurous acid from Experiment No. 8.

Procedure:

Mix the KClO_3 and the O_2 and place in ignition-tube. Attach rubber tube to side neck of tube. Place cork lightly in top of tube. Apply heat gently. Oxygen will be generated and pass out through rubber tube. Test for O by holding a match that has been lighted and extinguished, but still has a spark. The latter will glow brightly and reignite the match in the O . Conduct this oxygen into sulphurous acid made as in Experiment No. 8. The oxygen will combine and produce H_2SO_4 . The reaction is



EXPERIMENT No. 10.

To illustrate the formation of an *ite* salt (paragraph 48).

Apparatus and Materials:

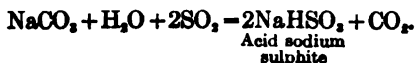
1. Material and apparatus for making SO_2 (a, Experiment No. 5).¹
2. Sodium carbonate in solution in water.

¹ Instead of generating SO_2 by burning sulphur, it may be obtained from sulphuric acid as follows: Arrange a Woulfe bottle with rubber tube on one neck. Place some copper filings on the bottom of the bottle. Add H_2SO_4 through the other neck until the filings are well covered. Close the latter neck of the bottle with a rubber cork. Heat gradually and carefully. Bubbles of SO_2 will soon rise and pass out through the rubber tube. The reaction is

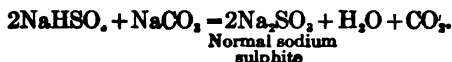


Procedure:

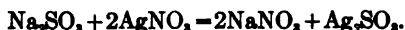
- (a) Place a small quantity of the solution of sodium carbonate in a small beaker. Pass the gas SO_2 into the solution of sodium carbonate. Sodium sulphite will be formed. The reaction is



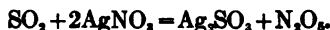
- (b) If more NaCO_3 be added to the solution of acid sodium sulphite, the normal sodium sulphite will be formed. The reaction is



- (c) If the normal sodium-sulphite solution be mixed with a solution of a non-alkali metallic salt, the insoluble sulphite of the latter metal will be precipitated. The reaction is



- (d) Silver sulphite may be formed directly by passing the gas SO_2 into a solution of silver nitrate, the reaction is



EXPERIMENT No. 11.

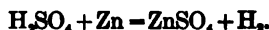
To illustrate the formation of an *ate* salt (paragraph 49).

Apparatus and Materials:

1. Small quantity of H_2SO_4 in a test-tube.
2. Zinc filings.
3. Beaker containing a little alcohol.

Procedure:

Drop zinc filings into the test-tube containing H_2SO_4 until bubbles cease to rise (heat gently if necessary). The H_2SO_4 has been changed to ZnSO_4 . The bubbles escaping are hydrogen. The reaction is



Since the sulphate of zinc is insoluble in alcohol, it will be precipitated as a solid if poured into the beaker containing alcohol.

v

EXPERIMENT No. 12.

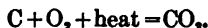
To illustrate a synthetical reaction (paragraph 27).

Apparatus and Materials:

1. Piece of charcoal.
2. Piece of sulphur.

Procedure:

- (a) Hold charcoal in flame of lamp or gas. It will glow and waste away, illustrating "combustion." The carbon of which charcoal is constituted combines with the oxygen of the air, forming CO_2 . The reaction is



- (b) Same as (b), Experiment No. 3.
(c) Same as (a), (b), (c), and (d), Experiment No. 1.

EXPERIMENT No. 13.

To illustrate an analytical reaction (paragraph 27).

Apparatus and Materials:

1. Small quantity of CaCO_3 .
2. Ignition-tube with rubber tubing attached to side neck.
3. Beaker containing lime-water.

Procedure:

Pulverize CaCO_3 , and fill the ignition-tube nearly half-full. Close top of tube. Heat gradually until gas passes out through rubber tube. This is CO_2 . If this gas be passed into the lime-water, it will become turbid from the reformation of the insoluble CaCO_3 . The reactions are

1. $\text{CaCO}_3 + \text{heat} = \text{CaO} + \text{CO}_2$.
2. $\text{CO}_2 + \text{Ca}(\text{HO})_2 = \text{CaCO}_3 + \text{H}_2\text{O}$.

All nitrates and all carbonates and sulphates, except those of the alkalies, are decomposed by heat, illustrating analytical reactions.

EXPERIMENT No. 14.

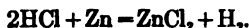
To illustrate a metathetical reaction (paragraph 27).

Apparatus and Materials:

1. Solution of silver nitrate.
2. Dropper.
3. Solution of common salt in a test-tube.
4. Zinc filings in a test-tube.
5. Hydrochloric acid.

Procedure:

- (a) Drop HCl on the zinc filings. The H is displaced, passing off as a gas and leaving ZnCl₂. The reaction is



- (b) Drop AgNO₃ into the solution of common salt. The solution will be filled with the white curdy precipitate of silver chloride (principle of insolubility). The reaction is



EXPERIMENT No. 15.

To illustrate the influence of temperature on the action of chemical affinity.

See Experiments Nos. 1 and 12.

EXPERIMENT No. 16.

To illustrate the influence of the liquid state on the action of chemical affinity (paragraph 116).

Apparatus and Materials:

1. Solid iron sulphate.
2. Solid barium chloride in a porcelain dish.
3. Solution of iron sulphate in a test-tube.
4. Solution of barium chloride.

Procedure:

Mix the solids in the porcelain dish. There will be no chemical action, however finely the substances be pulverized and mixed. Mix the solutions of the same substances by dropping a little of the barium chloride in the test-tube containing iron

sulphate. Instantly a reaction takes place, barium sulphate being formed as a white precipitate (principle of insolubility). The reaction is



EXPERIMENT No. 17.

To illustrate the influence of insolubility in producing reaction (paragraph 116).

(a) See last part of last experiment; also (b), Experiment No. 14.

(b) *Apparatus and Materials:*

1. Woulfe bottle with rubber tube attached to side neck.
2. Small quantity of iron sulphide, FeS .¹
3. H_2SO_4 .
4. Solution of lead nitrate in a test-tube.
5. Bottle of distilled water.

Procedure:

Place a small quantity of powdered FeS in Woulfe bottle. Add H_2SO_4 . Heat gently. H_2S , sulphydric acid, is formed and passes off as a gas through rubber tube. Collect in bottle of distilled water until water will absorb no more; this is sulphydric-acid solution. Drop a little of the sulphydric in the lead nitrate; instantly the black insoluble lead sulphide is formed as a black precipitate. The reaction is



EXPERIMENT No. 18.

To illustrate the influence of volatility in producing reactions (paragraph 116).

Apparatus and Materials:

1. Powdered CaCO_3 .
2. Powdered NH_4Cl .
3. A large test-tube.

Procedure:

Mix one part of CaCO_3 with two parts of NH_4Cl . Place mixture in the test-tube. Heat gently. Since the substances contain between them the constituents of the volatile salt ammonium

¹ FeS may be produced by mixing and heating together iron filings and powdered sulphur in a strong porcelain or earthen dish or in a crucible.

chloride, we find the principle of volatility operating and this salt formed and passes off as a gas; it may be condensed and collected as a solid by conducting it into a cooled receptacle. The reaction is



EXPERIMENT No. 19.

To illustrate the influence of the gaseous envelope (paragraph 116).

Apparatus and Materials:

1. Iron filings.
2. Small still or other apparatus for generating steam.
3. Rubber tube attached to still.
4. Glass tube attached to other end of rubber tube.
5. Woulfe bottle.

Procedure:

- (a) Set up the still with some water in it over source of heat. Place some iron filings in the glass tube, and connect latter with rubber tube. The bright iron filings will become oxidized to Fe_3O_4 , the black oxide of iron, and hydrogen gas will pass off out of the free end of the glass tube. That is, iron is oxidized in an atmosphere of water-vapor.
- (b) Substitute for the still the Woulfe bottle, with some HCl in the bottle. Drop in some zinc filings, generating H. Leave the Fe_3O_4 in the glass tube. The H will now pass out through the rubber tube over the Fe_3O_4 in the glass tube. Apply heat under the glass tube. The H will combine with the O of the Fe_3O_4 , passing off as H_2O vapor, leaving Fe behind, thus reversing the reaction in (a).

EXPERIMENT No. 20.

To illustrate catalytic action; that is, when a reaction appears to take place more readily, due simply to the presence of some substance, the latter undergoing no apparent change.

Apparatus and Materials:

1. KClO_3 .
2. MnO_2 .
3. Woulfe bottle with rubber tube attached.

Procedure:

- (a) Place some KClO_3 in Woulfe bottle and apply heat. Note the degree of heat required to decompose the KClO_3 .

- (b) Place a mixture of KClO_3 and about one-fifth its weight of MnO_2 in same bottle and apply heat. Note how much more readily the O passes off at a comparatively low temperature. The reaction is



This is the usual method of producing oxygen gas. Test O with match having a spark; its glow will be gently increased when O is coming off.

EXPERIMENT No. 21.

To illustrate the principle of "disposing affinity"; that is, a chemical reaction that is due to the presence of a third substance and the latter is decomposed.

Apparatus and Materials:

1. NaCl .
2. H_2SO_4 .
3. MnO_2 .
4. Woulfe bottle with rubber tube attached.

Procedure:

Place a mixture of NaCl and MnO_2 in the Woulfe bottle and add H_2SO_4 . Chlorine gas is given off, passing out through the rubber tube. If the experiment is tried without MnO_2 , HCl is produced instead of Cl . This is the usual method producing chlorine gas. The reaction is



If the MnO_2 is not present, the reaction is



EXPERIMENT No. 22.

To produce the alkalis (paragraph 58).¹

(a) Hydroxide of Potassium.

Apparatus and Materials:

1. Solution of potassium carbonate.
2. Clear filtered solution of slaked lime.
3. Glass funnel.
4. Small beaker.
5. Filter-papers.
6. Test-tube.

¹ See also Experiment No. 2.

Procedure:

Place a small quantity of the solution of potassium carbonate in a test-tube. Bring it to a boil over the flame. Add small quantity of lime-water. Calcium carbonate is precipitated as a white finely divided precipitate. Arrange a glass funnel and filter-paper over small beaker. Pour the clouded liquid on the filter-paper. The clear liquid that passes through is a solution of potassium hydroxide. It may be obtained in the solid form by evaporation.

(b) Hydroxide of Sodium.

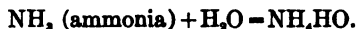
Hydroxide of sodium is produced in the same manner, using sodium carbonate instead of potassium carbonate.

*(c) Hydroxide of Ammonium.**Apparatus and Materials:*

1. Ammonia-gas, manufactured as explained in Experiment No. 29.
2. Distilled water.

Procedure:

Pass the ammonia-gas through a rubber tube into the distilled water. The water will absorb the gas, and the resulting liquid is ammonium hydroxide (ammonia-water). The reaction is



This substance exists only in the state of solution.

EXPERIMENT No. 23.

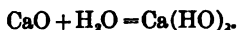
To produce the alkaline earths (paragraph 62).¹

*(a) Calcium Hydroxide.**Apparatus and Materials:*

1. Small portion of unslaked lime.
2. Distilled water.
3. Small porcelain bowl.

Procedure:

Place lime in the bowl and about half cover it with water. The process of slaking will proceed, the fat lime swelling, crumbling, and forming a white paste, which is the hydroxide of calcium. The reaction is



¹ See also Experiment No. 2.

If sufficient water be added to the hydroxide, it will be dissolved therein, forming the solution of calcium hydroxide or lime-water.

(b) *Barium Hydroxide.*

Apparatus and Materials:

1. Solution of barium nitrate.
2. Solution of sodium nitrate.
3. Arrangements for filtering.

Procedure:

Add the barium nitrate to the sodium nitrate, and filter the resulting turbid liquid. The insoluble filtrate is barium hydroxide.

EXPERIMENT No. 24.

To produce the hydroxides of other metals (paragraph 63).¹

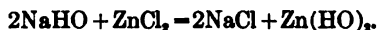
(a) *Zinc Hydroxide.*

Apparatus and Materials:

1. Solution of sodium hydroxide.
2. Solution of zinc chloride.
3. Test-tube.
4. Filtering arrangements.

Procedure:

Place a small portion of sodium hydroxide in test-tube and add a small quantity of zinc chloride. Zinc hydroxide will be formed as a white gelatinous precipitate. The reaction is



(b) *Iron Hydroxide.*

Method of procedure same as just explained, substituting iron chloride for zinc chloride. Iron hydroxide forms a white precipitate.

EXPERIMENT No. 25.

To produce oxygen.²

Apparatus and Materials:

1. Potassium chlorate.
2. Manganese dioxide.
3. Test-tube with rubber tube attached.

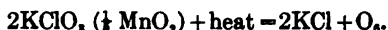
Procedure:

Heat a mixture of potassium chlorate with about one-fourth, by weight, of manganese dioxide in an ordinary test-tube. Oxygen

¹ See also Experiment No. 2.

² See also Experiment No. 20.

will be given off. Test for oxygen with a match with a spark at end. It will glow and ignite in the atmosphere of oxygen immediately above the test-tube. The reaction is



EXPERIMENT No. 26.

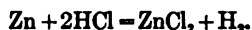
To produce hydrogen.

Apparatus and Materials:

1. Metallic zinc filings.
2. Hydrochloric acid.
3. Shallow porcelain dish.

Procedure:

To a small quantity of zinc filings placed on a porcelain dish add hydrochloric acid. Hydrogen is evolved rapidly as a gas. It will burn or explode on the application of a lighted match. The reaction is



EXPERIMENT No. 27.

To produce chlorine.

Apparatus and Materials:

1. Manganese dioxide.
2. Hydrochloric acid.
3. Test-tube.

Procedure:

Add hydrochloric acid to small quantity of manganese dioxide placed in test-tube. Chlorine is given off as a greenish-yellow gas having a very pungent odor. It has an acid action on blue litmus paper. It has bleaching properties, and will bleach filter-paper that has been stained in indigo solution. The reaction is



EXPERIMENT No. 28.

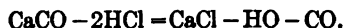
To produce carbonic-acid gas (carbon dioxide).

Apparatus and Materials:

1. Calcium carbonate.
2. Hydrochloric acid.
3. Small beaker.

Procedure:

Add hydrochloric acid to a small quantity of powdered calcium carbonate in a small beaker. Carbon dioxide will be given off rapidly as a gas. The reaction is



The gas may be detected by its taste and smell. Flame of lighted match introduced in the beaker is extinguished. Gas has acid action on blue litmus paper.

EXPERIMENT No. 29.

To produce ammonia-gas.

Apparatus and Materials:

1. Powdered ammonium chloride.
2. Powdered unslaked lime.
3. Small porcelain dish.

Procedure:

Intimately mix small quantity of the two substances in the porcelain dish and apply heat. The odor of ammonia-gas (NH_3) is soon detected. Moistened red litmus paper is turned blue if held in this gas, showing its alkaline action. The reaction is



EXPERIMENT No. 30.

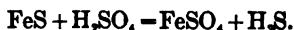
To produce hydrogen sulphide.

Apparatus and Materials:

1. Iron filings.
2. Roll sulphur.
3. Sulphuric acid.
4. Porcelain dish.

Procedure:

Mix a small quantity of iron filings with powdered roll sulphur in a porcelain dish and heat the same. Chemical combination takes place between the iron and the sulphur, forming iron sulphide (FeS). Add to this sulphuric acid, and gas is evolved which is hydrogen sulphide. It may be detected by its characteristic odor, which is that of decomposing flesh. The reaction is



EXPERIMENT No. 31.

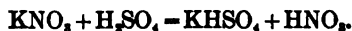
To produce nitric acid.

Apparatus and Materials:

1. A few crystals of potassium nitrate.
2. Small quantity of sulphuric acid.
3. Test-tube.

Procedure:

Place a few crystals of potassium nitrate in the test-tube. On addition of sulphuric acid, strong odor of nitric-acid vapor (HNO_3) will be detected. It gives acid reaction to blue litmus paper. The reaction is



EXPERIMENT No. 32.

To produce hydrochloric acid.

Apparatus and Materials:

1. Sodium-chloride solution.
2. Sulphuric acid.
3. Test-tube.

Procedure:

Place a small quantity of sodium chloride in a test-tube. On addition of sulphuric acid, the vapor of hydrochloric acid will be given off (HCl), which may be detected by its strong pungent odor. Gives acid reaction to litmus paper. The reaction is



EXPERIMENT No. 33.

To test any solution for a soluble chloride.

Apparatus and Materials:

1. A solution containing an unknown soluble chloride.
2. Small quantity of silver nitrate.
3. Test-tube.

Procedure:

Place a small quantity of the supposed chloride solution in the test-tube; add a drop of silver nitrate: if there be a chloride present in the solution, the insoluble silver chloride will be formed as a white curdy precipitate which turns black in the sunlight, and is soluble in ammonia-water.

EXPERIMENT No. 34.

To test a solution for the presence of a soluble sulphate.

Apparatus and Materials:

1. A solution containing an unknown soluble sulphate.
2. A solution of barium chloride.

Procedure:

Place in the test-tube a small quantity of the solution supposed to contain the sulphate; add a few drops of barium chloride solution: if a sulphate be present, the barium sulphate will be formed as a white finely divided heavy precipitate.

EXPERIMENT No. 35.

To test a solution for the presence of a soluble hydroxide.

Apparatus and Materials:

1. A solution containing an unknown hydroxide (hydroxides of the alkaline earths are soluble).
2. Small portion of zinc chloride in solution.
3. Test-tube.

Procedure:

Place in the test-tube a small quantity of the supposed hydroxide solution; add a small quantity of zinc chloride: if an hydroxide is present in the solution, zinc hydroxide will be formed as a white precipitate.

EXPERIMENT No. 36.

To test a solution for the presence of a soluble carbonate.

The carbonates of the alkalies are soluble.

Material and Apparatus:

1. A solution containing a soluble carbonate.
2. Calcium chloride.
3. Test-tube.

Procedure:

Place a small quantity of the supposed soluble carbonate in test-tube; add a small quantity of calcium chloride. Insoluble calcium carbonate will be formed as a white precipitate.

EXPERIMENT No. 37.

To test a solution for the presence of a soluble calcium salt.

Apparatus and Materials:

1. Small quantity of a solution containing the soluble calcium salt.
2. Small quantity of solution of ammonium carbonate.
3. Test-tube.

Procedure:

Place a small quantity of the supposed soluble calcium salt in test-tube; add small quantity of ammonium carbonate in solution. Calcium carbonate will be produced as a white precipitate.

EXPERIMENT No. 38.

To test a solution for the presence of a soluble nitrate.
All nitrates are soluble.

Apparatus and Materials:

1. Small quantity of solution of any nitrate.
2. Small quantity of solution of ferrous sulphate.
3. Small quantity of concentrated sulphuric acid.
4. Test-tube.
5. Copper filings.

Procedure:

- (a) Mix a small quantity of the ferrous sulphate and the supposed nitrate solution in a test-tube; add, carefully, a few drops of concentrated sulphuric acid: if a nitrate is present, a reddish-brown or purple layer will be formed at the junction of the sulphuric acid and the other liquid.
- (b) Introduce, in test-tube containing a supposed nitrate solution, a few copper filings, and add a few drops of concentrated sulphuric acid; apply heat carefully: dark reddish-brown pungent fumes of nitrogen peroxide (NO_2) will be evolved if a nitrate is present.

EXPERIMENT No. 39.

Test for solution containing a soluble iron salt.

Apparatus and Materials:

1. A solution containing a soluble iron salt.
2. A solution of ammonium sulphide.
3. Test-tube.

Procedure:

Place in the test-tube a small quantity of the supposed solution of iron salt; add a small quantity of the ammonium sulphide: if iron be present, the insoluble ferrous sulphide will be precipitated, first having a bluish color, which turns quickly to black.

EXPERIMENT No. 40.

To make an acetone colloid.

Apparatus and Materials:

1. Small quantity of acetone.
2. Small quantity of guncotton (cotton that has been dipped and allowed to steep for a few minutes in a mixture of nitric and sulphuric acid and afterwards cleansed by thorough washing in water).¹
3. Small beaker.
4. Small porcelain dish.

Procedure:

Dissolve a piece of the guncotton about the size of the little finger in about 55 c.c. of pure acetone; dissolve in the beaker; decant the solution into the shallow porcelain dish; evaporate to dryness over the flame, being careful to evaporate only to dryness and to avoid burning or igniting. A thin film of transparent colloid will be left on the porcelain dish. Note the difference in rate of burning by igniting first a small piece of raw nitrocellulose and then a piece of the dry colloid.

EXPERIMENT No. 41.

To make an ether-alcohol colloid.

Apparatus and Materials:

1. Small quantity of nitrocellulose, containing about 12.5 per cent of N.¹
2. Small quantity of ether and alcohol, in the proportion of 60 grams of ether to 20 grams of alcohol.
3. Small beaker.
4. Small porcelain dish.

Procedure:

Dissolve a piece of the nitrocellulose about the size of the little finger in a portion of the ether-alcohol solution placed in the beaker. Allow the nitrocellulose to become thoroughly dissolved. Decant the solution to shallow porcelain dish and evaporate carefully to dryness, avoiding igniting. A thin film of colloid is left on the dish. Compare the rate of burning of the colloid with that of unchanged nitrocellulose.

¹ See p. 142 et seq.

MATERIALS AND APPARATUS FOR LABORATORY DESK.

FOR USE IN CONNECTION WITH THE FOREGOING EXPERIMENTS.

Solution of sodium hydroxide	Barium nitrate, solution
Solution of potassium hydroxide	Sodium nitrate, solution
Solution of calcium chloride	Iron chloride
Solution of barium chloride	Potassium nitrate
Solution of copper sulphate	Silver nitrate
Solution of silver nitrate	Ammonium carbonate
Solution of ammonium sulphide	Ammonium sulphide
Hydrochloric acid	Nitrocellulose
Nitric acid	A piece of charcoal about 3" long and 1" square cross-section
Commercial sulphuric acid	Platinum foil $1\frac{1}{2}'' \times 1''$
Concentrated sulphuric acid	Platinum wire 3" long
Pure ether	1 test-tube rack
Pure alcohol	1 test-tube cleaner
Pure acetone	1 test-tube stand
A solution of ammonium carbonate and crystals	1 glass funnel
A solution of ammonium chloride and crystals	1 shallow porcelain dish
Calcium carbonate	1 porcelain crucible
Calcium oxide (fat lime)	1 porcelain mortar and pestle
Metallic iron, filings and turnings	1 Woulfe bottle
Metallic copper, turnings	6 test-tubes, assorted
Metallic zinc, strips	3 beakers, assorted
Metallic mercury	1 iron tripod
Metallic sodium	2 watch-crystals
Zinc chloride, solution	1 blowpipe
Roll sulphur	1 pair of tongs
Solution of indigo	1 pair of forceps
Metallic tin	1 spatula
Sodium chloride	1 glass dropper
Manganese dioxide	1 glass rod
Iron sulphate	1 test-tube holder
Barium chloride	1 asbestos pad
Solution of lead nitrate	1 water-bottle for distilled water
Iron sulphide	Filter-papers
Ammonium chloride	Litmus papers
Potassium chlorate	Source of heat: gas or lamp
Potassium carbonate	Rubber tubing
Sodium carbonate	Iron ring-support
Ammonia-water	Ignition-tube
	Small still

LABORATORY NOTES.

Throw all solid waste materials in the earthen crocks provided at each desk, and *not in the sinks*.

In rinsing apparatus containing acids, allow the water to run for a moment to dilute the acids and thereby protect the pipes.

When through with a source of heat, extinguish it.

Always keep the reagent-bottles in their proper places, with labels to the front.

In using a liquid reagent, grasp the stopper first between the little finger and palm of the hand, then grasp the bottle between the thumb and other fingers of the same hand, the label of the bottle being against the palm of the hand. Pour out slowly and carefully the smallest amount of reagent possible for the reaction and, at the last, touch the lip of the bottle against the edge of the vessel, so that the last drop will not run down the sides of the bottle. *Replace the stopper and put back the bottle at once*. Neither bottle nor stopper should ever be put on the table.

Dry reagents and the more unusual wet reagents should be kept on a separate stand for general use.

All glass and porcelain articles should be cleansed immediately after using, and in no case left or put away dirty.

In performing experiments which give rise to pungent or offensive fumes, such as NO_2 , SH_2 , etc., go to the hood and perform the experiment there.

On leaving the laboratory, be careful to label distinctly any solution or substance which is to be further examined or used, and mark the slip with the word "preserve" and your name.

Leave the desk in order so that the attendant may dust it and clean it.

If a solution has to be put aside even for a few minutes, *label* it over your initials.

Laboratory notes may be entered either in rough form on

a pad to be entered later in the note-book, or directly in the note-book. The latter is the better method. Time is too valuable to spend it in *copying*.

Lecture-notes in abbreviated form must, of course, first be taken down in rough and then *expanded* into the note-book, but a distinction should be drawn between *mere copying* and *expansion of abbreviated notes*.

When a glass stopper sticks tightly, heat the neck gently and gradually, keeping the stopper entirely out of the flame. Then press the stopper gently from side to side. While heating the neck, turn it round and round in the flame.

Test-tubes are little cylinders of thin glass, closed at one end, in which most tests and liquid reactions are conducted. They vary in size from 4 to 8 inches long and from $\frac{1}{2}$ to $\frac{3}{4}$ inch in diameter. They should not be so large in diameter that the open end may not be closed by the thumb. They may be used for heating liquids in a flame, holding either in the bare fingers, or, if too hot, in a test-tube holder.

Two precautions must always be observed in heating test-tubes and all glass vessels.

1. The outside should be wiped perfectly dry just before placing in the flame.
2. The tube should be brought gradually into the flame and moved in and out and rolled between the finger and thumb, so that the heating shall be *gradual and uniform*.

The reactions which take place in test-tubes, and the boiling of liquids therein, often cause portions of the liquid to be ejected. To guard against accident from this cause, the operator should never hold the mouth of the tube toward himself or another person near him.

Test-tubes are cleaned by a *test-tube cleaner*, consisting of a bunch of bristles caught between twisted wires and a small piece of sponge held at the end, or a round end of bristles.

Test-tubes are kept in *racks*, a set of holes being provided for tubes in use, and a set of *draining-pegs* for those not in use.

These racks usually contain a dozen tubes. The tubes should be thoroughly washed before placing on the pegs.

Flasks are bottle-shaped glass vessels having a neck and globe; the latter may have a round or flat bottom. They are used for boiling liquids in, and are often placed in iron ring supports over the source of heat. The same rules as to heating and cleaning apply to these as to test-tubes. In arranging flasks for experiment, *be careful to allow sufficiently large exit for gases generated*—an explosion of a flask is liable otherwise.

Beakers are thin glass, open, tumbler-shaped vessels with a flare edge and, often, a small spout. They are used chiefly to receive filtered liquids, or for reactions on a larger scale than in test-tubes.

Glass funnels should be thin and light and have the throat cut off obliquely. Their sides should incline at 60° , the most favorable angle for filtration. They are used for transferring liquids from one vessel to another, and for holding filter-papers. Agate-iron, iron, and porcelain funnels are also furnished for rougher work.

Some funnels are arranged with corrugations or cut channels specially to accelerate filtering.

Filtering-papers are used to separate the precipitates from the liquids in which they were formed; the latter, after separation, is often called the *filtrate*. A good filter-paper should be porous enough to filter rapidly and yet sufficiently close in texture to retain the finest powder. The paper should be strong enough to bear when wet the pressure of the liquid poured on it. Good filter-paper should be free from all salts and as near pure cellulose as is possible; when burned, it should leave a very small proportion of ash. White paper is more likely to fulfill these conditions than the colored varieties.

Filter-paper comes in sheets, but cut filter-papers are supplied as a rule. The separate papers are in circular form.

Small papers and funnels should be used in experiments. A paper about three inches in diameter is the most convenient size, except for reactions involving large quantities of materials.

A filter is prepared for placing in a funnel as follows:

1. Fold across on one diameter.
2. Fold each end of semicircle back on 45° radius.
3. Fold each of the 45° folds in its middle.
4. Open out between the folds.

Or a second method is as follows:

1. Fold across a diameter as before.
2. Fold across the semicircle on the 90° radius.
3. Open out 3 layers on one side and 1 on the other.

The first method is the better, as it gives quicker filtration.

Filter-papers are placed in funnels so as to fit closely to the sides, and after they are in place they are wetted down with distilled water, using a wash-bottle for this purpose. Some funnels are grooved to favor filtration. The rate of filtering may be increased by using larger filter-papers or by lengthening the throat of the funnel and letting it dip down into the filtrate.

Strong acid or alkaline solutions should be filtered through asbestos wool placed in the throat of the funnel.

A filter-paper of less than 2 inches in diameter may be placed directly in the mouth of a test-tube, and those between 2 and 3 inches may be placed in a funnel and the funnel placed directly in the mouth of the test-tube without other support.

When, however, a large quantity of liquid is to be filtered, larger papers are necessary and larger funnels; these latter are supported in *stands* or *rings* independently of the vessel arranged to receive the filtrate. A beaker or a porcelain dish may be arranged to receive the filtrate. Care should be taken that the lowest point of the throat of the funnel touches the side or edge of the vessel, in order that the liquid passing through may not fall in drops, but run quietly down the side without splashing.

Porcelain *evaporating-dishes* of various sizes are used. These dishes will bear the heat of a lamp- or gas-flame without cracking. The best are the "Berlin" dishes glazed on both sides. With these dishes a solution may be evaporated to dryness, or even to ignition over the open flame of a lamp- or gas-burner. It is well, however, to support the dishes in such cases

on a piece of iron wire gauze; otherwise the dish may be supported on a small wire triangle.

Porcelain crucibles are made of very thin porcelain and may be subjected to even higher heat than the dishes. They are made with covers. They are supported over the flame by small wire triangles.

Both porcelain dishes and crucibles should be brought gradually to the full heat.

Two kinds of lamps are used—the common *spirit-lamp*, and the circular-wick lamp, also known as the *Berzelius lamp*. The former is used for ordinary heating of test-tubes, etc.; the latter when a higher temperature is required and a larger flame, especially for water- and sand-baths, for evaporation, and ignition of residues. Spirit-lamps, when not in use, should be covered over to prevent evaporation.

Supports.—Several forms of supports are used in heating:

1. The *iron tripod*, consisting of a ring to which three legs are attached. The flask, dish, or crucible is supported on this ring and the lamp is placed below. The proper height is given by wooden blocks, either blocking up the tripod or the lamp.
2. The *iron-rod support* consists of an iron rod attached to a heavy cast-iron base. Several rings of different diameters are secured to the rod by binding-screws, and may be adjusted vertically and laterally, like the stand of the Berzelius lamp.
3. *Iron-wire gauze*—a piece about 6 inches square.
4. *Iron-wire triangle*—three pieces of iron wire formed into an equilateral triangle, with the wires twisted together at the vertices for a distance of an inch or two.

A *water-bath* consists of a copper vessel with a set of covers of different diameters. It is used to evaporate at moderate heat, or to dry precipitates or other substances which must be kept below a certain temperature. This temperature is fixed by the boiling-point of the liquid placed in the bath. If, for example, an aqueous solution is to be evaporated without

ebullition, it must not rise above the boiling-point of water, nor even quite to reach that point. To accomplish this, fill the bath two-thirds full of water, place on those particular cover rings that will permit the greater part of the dish containing the solution to be below the cover but not in the water of the bath. Support the bath on either the tripod or ring support and apply the heat. The dish holding the solution is thus heated by an atmosphere of steam, and the temperature will not exceed 212° F. The water in the bath must never be allowed to boil away. There are several modifications of the water-bath.

If a gradual and uniform temperature higher than the water-bath be desired, this may be accomplished by the *sand-bath*. This consists simply of a shallow dish or pan in which sand is placed, and the body to be heated is placed in a dish on this sand. The thickness of the sand layer regulates the temperature for a given flame.

The blowpipe is used to oxidize and deoxidize samples and to give a high degree of heat. Deoxidization is often called "reduction."

In using the blowpipe, the air should be forced from the lungs into the mouth-cavity, distending the cheeks, and the air then forced through the blowpipe by the muscles of the cheeks. A steady uniform pressure may thus be maintained.

For oxidization purposes the sample should be held just beyond the tip of the outer luminous flame; for reducing purposes it should be held at the tip of the inner blue flame. The hottest part of the blowpipe flame is between the luminous and blue flame; for melting metals, and when a high degree of heat is desired, the sample should be held at this point.

Specimens may be supported and held before the blowpipe either on charcoal, on platinum-foil, or on a platinum loop.

- (a) On charcoal: Take a piece of charcoal about 3"×1"×1". Near the end of one of the longer faces cut with knife or scraper a small depression about $\frac{1}{4}$ " diameter and $\frac{1}{4}$ " deep. Place the sample in this depression.

Hold the charcoal between the thumb and forefinger of the left hand, slanting at about 30° downward; the sample being at the lower end. Present the sample to the blowpipe in this position.

- (b) On platinum-foil: Take a piece of platinum-foil about $1\frac{1}{2}$ " by 1". Clean its surface with moist sand. If wrinkled, rub out the wrinkles on the bottom of the agate mortar, using the agate pestle. Bend over one corner slightly. Take hold of this corner with the forceps. Place the sample on the foil. Present to the flame, holding the forceps in the left hand.
- (c) Platinum wire loop: Fuse a fine platinum wire to the end of a glass rod. Straighten out all kinks in the wire by making a single loop over a round lead-pencil or other similar article, and pulling the pencil along the wire without turning. Make a small circular loop at the end of the wire about $\frac{3}{8}$ " in diameter. Heat the loop to red heat, and wipe after cooling with clean filter-paper. Prepare the sample with proper fluxes, place it on the loop and present to the blowpipe.

Never heat any metal or any substance from which a metal can be reduced on platinum, as the latter forms alloys with other metals, which alloys have a lower fusing-point than platinum and injure its properties otherwise. The alkaline sulphides and hydroxides also act on platinum. It is dissolved by aqua regia and chlorine-water.

Wash-bottle.—This is a large bottle of distilled water for general use in carrying out experiments. It is used particularly for diluting specimens in test-tubes, for wetting down filter-papers so they will adhere closely to the sides of funnels, for washing down precipitates from the sides of vessels, and for washing precipitates. Two tubes enter the bottle through a rubber cork. One is straight and projects about 4" above the cork, and the other at a point about 1" above the cork is bent sharply downward at an angle of about 45° , and terminates

at about 4" from the bend in a pointed aperture. The first tube stops inside of the bottle above the surface of the water, the bent tube extends inside the bottle well down to near its bottom.

The water is poured out through the straight tube, holding the bent tube uppermost.

By blowing down the straight tube, using some little force in the act, the water is forced up through the bent tube and out at the pointed aperture.

Glass Tubing.—Various sizes of glass tubing are used; the larger sizes for joining parts of apparatus, in connection with rubber-tubing; the smaller sizes for exits through corks from bottles and large test-tubes. A piece of small-caliber glass tube is used as a dropper. The tube, when used for this purpose, must be perfectly clean. It is inserted in the reagent-bottle, the reagent rises in the tube, the end of the finger is placed over the top and the tube then withdrawn, bringing with it the small quantity of reagent held in the tube.

Ordinary glass tubing may be cut in the simplest way by placing it lengthwise in a V trough, the point to be cut resting just beyond the trough; passing a diamond around at the point with one hand, holding the tube tightly with the other, then grasping the tube firmly with both hands on either side of the cut and near it, break the tube at the cut by turning the hands evenly, upward and outward, using the necessary force.

The sharp corners of the ends of glass tubing may be rounded by holding in the Bunsen or alcohol flame. This should always be done before attempting to insert a tube in corks or in rubber tubing, as the tube inserts much more easily if the corners are rounded. Care should be exercised not to change the size of the orifice. It will be sufficient to bring the very outer edges to a good red heat and rub a second heated rod gently over these edges.

Very thin glass tubing, which cannot be cut as described above, may be cut by filing a slight cut at the point, then apply gradually a hot point progressively around the tube, starting

at the file-cut. It may be necessary sometimes to chill the tube at the file-cut by placing it in cold water or ice for a minute or so, and then wiping dry, before applying the heated point.

Glass tubes are bent by heating them over a flame until plastic, then bent carefully with force applied very slowly; only the heat necessary should be used.

To close a glass tube, heat the end until plastic, press together opposite points of circumference until they meet, make weld complete, then shape.

To form a bulb in a glass tube, heat the tube in the point at which it is desired to have the bulb until the glass is plastic at that point. Blow through the tube, using sufficient force to cause the plastic glass to expand to the size desired.

To make an opening in the side of a glass tube, heat the tube at the point until the glass there is plastic. Perforate the side with a glass rod, open the perforation to the size desired, round off and smooth the edges.

Rubber tubing of various sizes is used to connect the glass and metal parts of apparatus. There is a great advantage in this means of connection by reason of the pliability of the tubing, the air-tight joints that are made, and the fact that alkalies and dilute acids do not act on rubber.

The cork-borer consists of a nest of metal tubes of various sizes, with one end bevelled to a cutting circular edge. It is used to bore holes through rubber and cork stoppers for glass tubes.

In *putting a glass tube through a bored stopper*, see that the edges of the tube have been rounded by heating, grasp the tube firmly, close to the stopper, press in easily and directly along the axis of the tube with a screw motion. Wet the tube with alcohol or with soap-suds, if it moves with great difficulty. Avoid lateral pressure. Do not hold the body of a funnel in forcing the neck through a stopper nor a bent tube at the bend.

Rubber stoppers are used when absolutely air-tight closing of bottles is important. They may be perforated for glass tubes

by a brass cork-borer; the latter should be moistened with alcohol to facilitate the process. They have a further advantage over cork stoppers by reason of the non-action of alkalis and weak acids.

Sheet rubber is used to make tight joints between glass tubes of different sizes, or between the neck of a bottle or a flask and a large glass tube entering it.

Cork stoppers should be softened by rolling or squeezing before using. There is difficulty in finding perfectly round corks; eccentric parts may be removed by using a fine flat file. The size of corks may be reduced somewhat by squeezing or filing or both.

Double-neck bottles are convenient for generating gases; one neck being used for the reagent, and the other, with glass tube and rubber tubing attached, for transferring the gas generated.

There are four kinds of *mortars* in common use: (1) an *iron mortar*, for heavy material requiring great strength to pulverize; (2) *porcelain mortars*, for ordinary solid reagents; (3) *agate mortars*, for minerals and reagents having high degree of hardness; (4) *diamond mortar*, consisting of small steel cylinder, anvil, and piston, in which very hard and tough materials are pulverized or broken before using the agate mortar.

Spatulas are thin, knife-like blades made of steel, horn, or porcelain. They are used in handling solid reagents and samples.

Watch-glasses are used in pairs, with a suitable metal clasp to hold them tightly together, in holding samples for weighing, drying, and for preserving them safely from loss or change during experimentation.

The clothing should be covered by overalls or aprons during laboratory work. In case strong acid gets on the clothing or skin, it should be neutralized at once with ammonia-water or other strong base, or washed for some time in running water.

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REGULATIONS FOR THE TRANSPORTATION OF EXPLOSIVES.

[APPROVED BY THE AMERICAN RAILWAY ASSOCIATION].

General Notice.¹—The safe transportation of explosives is largely influenced by the manner in which they are made and packed for shipment, as well as by the careful and intelligent handling of them by railway employes. Information in regard to the kind of explosives is necessary so that railway employes may not ignorantly incur danger or endanger the lives and property of the public.

Shipments made by the United States Government² will be accepted upon the certificate of an army or navy officer or duly authorized non-commissioned or warrant officer that the shipments are made in accordance with United States Government regulations, including limitations of weight, for which the form of certificate entitled "United States Government Certificate of Explosives Offered for Transportation" will be used and kept on file.

Other explosives, except such as are forbidden, will be received for transportation, provided the following regulations are complied with, and provided their method of manufacture and packing, so far as it affects safe transportation, is open to inspection by the proper officers of the company transporting the explosives.

Shipments of explosives destined to points beyond the lines of the receiving company will only be accepted subject to

¹ See Interpretation No. 1, page 302.

² All the following regulations must be observed for Government shipments, except as to packing and weights provided for other shipments.

the regulations of the roads over which the shipments are to be moved. Shipments offered by connecting lines will be received subject to the following regulations:

1. **Classification.**—Explosives are divided into the following groups:

1. Forbidden Explosives.
2. Common Black Powder.¹
3. High Explosives.
4. Smokeless Powders.
5. Fulminates.
6. Ammunition.
7. Fireworks.

2. **Group 1—Forbidden Explosives.**—Liquid nitroglycerine, dry guncotton (except as made up in ammunition), high explosives containing over sixty per cent of nitroglycerine (except gelatine dynamite), and fulminates in bulk in a dry condition, must not be accepted for transportation.

3. **Group 2—Common Black Powder.**²—Common Black Powder embraces all explosives having the constituents of ordinary gunpowder or similar in composition. This group includes rifle, sporting, blasting, cannon, and the prismatic powders.

Packing.—Packages containing less than twenty (20) pounds of rifle, sporting, blasting, or cannon powders must be inclosed in a wooden box so that the filling-holes of the packages will be up.

Prismatic powders must be packed in tight tin boxes, which must be inclosed in a wooden box.

Twenty (20) pounds or over of common black powder should be packed in a wooden keg or cask. Iron or steel kegs or casks will be received. These iron or steel kegs or casks must be so made and the filling-hole so secured that, when filled with sand and dropped in any manner a dis-

¹ Includes all ordinary "charcoal" powders.

² See Interpretation No. 2, page 302, and No. 9, page 303.

tance of four feet on a rail, they will not rupture, nor will any of the sand escape.

Weight.—Packages containing over 115 pounds net will not be received.

Marking.—Each box, cask, or keg must be plainly marked "COMMON BLACK POWDER."

4. **Group 3—High Explosives.**¹—High Explosives are all explosives more powerful than ordinary black powder, except smokeless powders and fulminates. They are known under various trade names, such as Acme, Ætna, Atlas, Climax, Commercial, Dittmar, Dynamite, Forceite, Fumeless, Giant, Hecla, Hercules, Joveite, Big Chief, Judson, Masurite, Samson, Rend-Rock, Rack-a-Rock, etc.

5. NO HIGH EXPLOSIVE CONTAINING OVER 60 PER CENT OF NITROGLYCERINE WILL BE RECEIVED, EXCEPT GELATINE DYNAMITE. Explosives like Rack-a-Rock, one constituent of which is liquid, will be accepted if the liquid is not explosive and is not packed in the same boxes with the other constituent.

High explosives consisting of a liquid combined or mixed with an absorbent material must have the absorbent material properly dried before mixing, and the ingredients uniformly mixed so that the liquid constituent is thoroughly absorbed. Explosives containing nitroglycerine must have a satisfactory kind of antacid in the absorbent material equal to one per cent or over of the weight of the latter.

Packing.—High explosives must be made into cartridges and not packed in bags or sacks. Bags or sacks of Judson powder containing not over 12½ pounds each will be considered cartridges. The covering of the cartridges, consisting of paper or other material, must be so treated that it will not absorb the liquid constituent of the explosive. Boxes should be painted on the inside or lined with paraffin paper, or otherwise treated so that the liquid

¹ See Interpretations Nos. 3 and 5, pages 302, 303.

constituent of the explosive will not be absorbed by the wood.

The cartridges must be so arranged in the boxes that when they are transported all cartridges will lie on their sides and never on their ends.

The boxes must be strong and made of lumber not less than one-half inch in thickness, and with ends one inch in thickness, and not too large to be readily handled by one person.

Weight.—Packages containing over fifty (50) pounds net will not be accepted.

Marking.—The boxes must be plainly marked on top and on one side or end "HIGH EXPLOSIVE—DANGEROUS." The position in which the cartridges lie in the boxes must also be indicated thereon.

6. Group 4—Smokeless Powders.—Smokeless Powders are those explosives from which there is little or no smoke when fired. This group consists of (A) smokeless powder for army and navy use; (B) smokeless powders, known also as wood powders, for rifle or shotgun use in which guncotton or nitro-cellulose is the principal ingredient; (C) the picrate powders, such as Velox and Gold Dust; and (D) wet guncotton for torpedoes and army use.

7. (A) Smokeless Powder for army and navy use.

Packing.—Smokeless powders must be packed in tight wooden boxes free from knot-holes or cracks.

Weight.—Packages must not weigh over 115 pounds net.

Marking.—Each package must be plainly marked on top "SMOKELESS POWDER—KEEP FIRE AWAY."

8. (B and C) Smokeless Powder for rifle or shotgun use.

Packing.—Packages containing less than ten (10) pounds must be inclosed in a wooden box so that the filling-holes of the packages will be up.

Ten (10) pounds or over should be packed in a wooden keg or cask. Iron or steel kegs or casks will be received. All kegs unless boxed must measure not less than 9 inches

in diameter and $10\frac{1}{2}$ inches in length or have equivalent contents. These iron or steel kegs or casks must be so made and the filling-hole so secured that, when filled with sand and dropped in any manner a distance of four feet on a rail, they will not rupture nor any of the sand escape.

Weight.—Packages containing over 115 pounds net will not be received.

Marking.—Each box, cask, or keg must be plainly marked on top "SMOKELESS POWDER—KEEP FIRE AWAY."

9. (D) **Wet Guncotton.**

Packing.—Wet guncotton must be packed in tight wooden boxes free from knot-holes or cracks. These boxes must be so well constructed or the guncotton so inclosed in paraffin paper or other impervious material that it will not dry out during transit so as to contain less than fifteen (15) per cent of water upon its arrival at destination.

No guncotton is to be received for shipment unless it contains twenty (20) per cent of water.

Weight.—Packages weighing over 220 pounds gross must not be received.

Marking.—Guncotton must be plainly marked on top "GUNCOTTON—WET."

10. **Group 5—Fulminates.**—This includes **Fulminate of Mercury** or other fulminates in bulk form—that is, not made up into percussion-caps, detonators, blasting-caps, or exploders.

Packing.—Fulminate of mercury in bulk must contain when packed not less than twenty-five (25) per cent of water and must in this wet condition be placed in a twelve-ounce duck bag and securely tied. This duck bag must be placed in a rubber bag, which rubber bag must be filled with water and securely tied. The rubber bag and contents must then be placed in a tight cask, the empty spaces around the bag filled with sawdust, the cask closed and filled with water and then sealed.

Marking.—Each cask must be plainly marked “FULMINATE—HANDLE CAREFULLY.”

11. **Group 6—Ammunition.**—Ammunition consists of three classes: small-arms ammunition and great-gun ammunition, both in the form of cartridges; and detonators, blasting-caps, percussion-caps, fulminators, exploders, etc.

12. Small-arms ammunition consists usually of a paper or metallic shell which contains the primer, explosive, and projectile, the materials necessary for one firing being all in one piece, to be used in sporting- or fowling-pieces or in rifle and pistol practice, etc.

Packing.—Small-arms ammunition to be used in sporting- or fowling-pieces or in rifle and pistol practice, etc., must be packed in pasteboard or other boxes, and these pasteboard or other boxes must be packed in strong wooden boxes.

Marking.—Each package or case must be plainly marked “SMALL-ARMS AMMUNITION.”

13. **Great-gun ammunition** embraces all fixed ammunition in which the projectile weighs one pound or over, and is usually transported only for Government use.

Packing.—This form of ammunition must be packed and properly cushioned in strong wooden boxes, small and light enough to be readily carried by not more than two men.

Marking.—Each package or case must be plainly marked “GREAT-GUN AMMUNITION—HANDLE CAREFULLY.”

14. **Ammunition in other form than cartridges**, such as detonators, blasting-caps, etc., must be packed in strong, tight wooden boxes, and must not be placed near other explosives.

Marking.—Each package must be plainly marked with the name of the article inclosed and the words “HANDLE CAREFULLY,” as, for instance, “DETONATORS—HANDLE CAREFULLY,” “PERCUSSION-CAPS—HANDLE CAREFULLY,” etc.

15. **Group 7—Fireworks.**—Fireworks embrace everything that may be used to produce pyrotechnic effects. This group

includes serpents, rockets, bombs, shells, mines, batteries, wheels, Roman candles, maroons, fountains, quick matches, fire-crackers, squibs for firework use, colored fires of all grades, and every class of firework composition or exhibition pieces, and also torpedoes or track-caps, fuses, fog-signals, etc.

Packing.—Fireworks must be securely packed in strong, tight wooden boxes in such manner that the ordinary shocks of transportation will not cause the articles to change position inside the box.

Marking.—Each box or package must be plainly marked "FIREWORKS—HANDLE CAREFULLY—KEEP FIRE AWAY."

16. Selection and Preparation of Cars.¹—For the transportation of common black powder, high explosives, smokeless powders, fulminates, and great-gun ammunition, ONLY BOX-CARS IN GOOD CONDITION, OF NOT LESS THAN 60,000 POUNDS CAPACITY, MUST BE USED. STEEL UNDER-FRAME BOX-CARS ARE RECOMMENDED.

17. In all cases the cars must be as follows:

(a) Equipped with air-brakes and hand-brakes in condition for service.

(b) Must have no loose boards, or cracks in the roof, sides, or ends.

(c) The doors must shut so closely that no sparks can get in at the joints, and if necessary must be stripped.

(d) The journal-boxes and trucks must be carefully examined and put in such condition as to reduce to a minimum the possibility of hot-boxes or other failure necessitating the setting off of the car before reaching destination. The car must be carefully swept out before it is loaded.

(e) Holes in the floor or lining must be repaired and special care taken to have no projecting nails or bolts or pieces of metal which may work loose and produce holes in packages of explosives during transit.

(f) Short pieces of hard wood, two-inch plank, must be

¹ See Interpretation No. 6, page 303.

spiked to the floor over the king-bolts, or draft-bolts, to prevent possibility of their wearing through the floor and into the packages of explosives.

(g) Agent or inspector must examine cars and sign "Certificate of Inspection of Car Containing Explosives" upon the prescribed form before permitting the cars to be loaded or despatched. The certificate must also be signed by the shipper.

18. Small-arms ammunition, detonators, etc., and fireworks must be loaded in a box-car in good condition, so tight as to prevent the entrance of sparks into the car. Cars containing small-arms ammunition, detonators, etc., and fireworks do not require the "Certificate of Inspection of Car Containing Explosives," but cars containing fireworks should be carded "INFLAMMABLE—KEEP LIGHTS AND FIRES AWAY." The shipper of these articles must execute and deliver to the station agent the "Manufacturer's Certificate" or the "Shipper's Certificate" upon the prescribed form.¹ The station agent must make the proper note upon the billing to show that he has the certificate on file.

19. **Placarding of Cars and Certification of Contents.**—The prescribed forms of cards and certificates must be used.

20. Every car containing common black powder, high explosives, smokeless powders, fulminates, or great-gun ammunition, *in any quantity*, must be plainly carded on both sides and both ends "EXPLOSIVES—HANDLE CAREFULLY—KEEP FIRE AWAY."

The agent will be held responsible if a car containing these explosives leaves his station or a siding within his jurisdiction without having these cards properly affixed.

21. MANUFACTURERS shipping common black powder, high explosives, smokeless powders, fulminates, and great-gun ammunition, and SHIPPERS of great-gun ammunition in carloads or less than carloads, will be required to properly fill out and sign

¹ The "United States Government Certificate of Explosives Offered for Transportation" must be used for shipments made by the Government.

the "Manufacturer's Certificate of Contents and of the Method of Packing and Marking Packages of Explosives" for each shipment on the prescribed form, which, when signed in writing, must be delivered to the station agent.¹ All other shippers shipping common black powder, high explosives, smokeless powders, fulminates, and great-gun ammunition, must sign in writing the "Shipper's Certificate of Explosives Offered for Transportation" on the prescribed form, covering the words, "These explosives are in the original packages as manufactured," which form must be delivered to the station agent.

Shippers must procure the prescribed forms of certificates and cards from the station agent.

The agent on receipt of the Manufacturer's or the Shipper's Certificate¹ must indorse the back of the card way-bill and revenue way-bill to show that this certificate has been duly executed and filed; thus:

Certificate covering this property
duly executed and filed at this
(.....)
Station.
.....19..

The "Manufacturer's Certificate" or the "Shipper's Certificate"² will be filed by the station agent at the station at which the shipment originated.

22. Shipments from Connecting Lines.—Agents at junction points may receive and forward cars carded as prescribed in

¹ The United States Government, when shipping common black powder, high explosives, smokeless powders, fulminates, and great-gun ammunition will be required to properly fill out and sign the "United States Government Certificate of Explosives Offered for Transportation" for each shipment on the prescribed form, which when signed in writing must be delivered to the station agent. (See General Notice.)

² The "United States Government Certificate of Explosives Offered for Transportation" will be used for shipments made by the Government.

Rule 20 as containing explosives, from connecting lines known to have adopted these regulations, without the "Manufacturer's Certificate" or "Shipper's Certificate"¹ and without the "Certificate of Inspection of Car Containing Explosives" being presented; but these certificates must be furnished to the receiving road when requested.

Agents, when in doubt as to whether the lading is properly stowed or not, will inspect the contents to ascertain the condition of the lading.

23. Handling of Explosives.—In handling packages of explosives at stations and in cars, the greatest care must be taken to prevent their falling or getting shocks in any way, and they must not be thrown nor dropped, but must as far as practicable be passed from hand to hand, or carried by one or more persons, and must not be rolled on the platform or car floor, nor handled on trucks, unless they are so heavy that this cannot be avoided.² The agent must choose careful men to handle explosives, must see that the platform and feet of the men are as free as possible from grit, and must take all possible precautions against fire. No unauthorized person must have access to the explosives at any time while they are on the property of the Company. Should any packages of high explosives when offered for shipment show excessive dampness or be mouldy, or show outward signs of any oily stain or other indication that absorption of the liquid part of the explosive in the absorbent material is not perfect, or that the amount of the liquid part is greater than the absorbent can carry, THE PACKAGES MUST BE REFUSED IN EVERY INSTANCE, AND MUST NOT BE ALLOWED TO REMAIN ON THE PROPERTY OF THE COMPANY.

24. Loading in Car.—Boxes of high explosives must be so loaded in the car that the cartridges will be on their sides and never so that the cartridges will be on end.

All other boxed explosives must be loaded with the boxes top side up. Explosives packed in round kegs, except when

¹ See note 2, page 295.

² See Interpretation No. 7, page 303.

boxed, must be loaded on their sides in rows across the car if there is more than one tier.

Larger casks, barrels, or drums may be loaded on their sides or ends as will best suit the conditions. Whatever the kind or form of the packages, after they are loaded THEY SHALL BE SO STAYED THAT THEY CANNOT CHANGE POSITION UNDER THE ORDINARY SHOCKS OF TRANSPORTATION. Special care must be used so that they cannot fall to the floor or have anything fall on them during transit.

25. Black powder, high explosives, and smokeless powder of all kinds, may be loaded together in the same car. Fulminates, ammunition, both small-arms and great-gun, and detonators, etc., and fireworks must never be loaded with each other, nor in the same car with common black powder, high explosives, or smokeless powder. All kinds of fireworks may be loaded together in the same car.

26. "Friction matches" or other articles of like nature, acids, chemicals, gasoline, naphtha, benzine, etc., must not be loaded in the same car with common black powder, high explosives, smokeless powders, fulminates, great-gun ammunition, or fireworks, nor when unloaded be put near those explosives. Care must be taken that other freight in the car is so loaded and stayed that there is no danger of the packages of explosives being broken during transit.

27. **Safety Fuse and Safety Squibs.**—Safety fuse and safety squibs will be accepted for shipment at any time they are offered, and the restrictions in regard to shipping powder do not apply to them. These articles, provided they are properly boxed, may be loaded in the same car with other explosives.

28. **Handling Cars Containing Explosives.**—The following rules must be observed by yard and train employes in the making up and movement of freight-trains and the handling of cars carded as containing explosives.

(a) Cars carded as containing explosives must not be hauled in a train carrying passengers.

(b) The conductor must under no circumstances take

a car containing explosives from a station, including transfer stations, or a siding unless it is properly carded as per Rule 20, and unless the car appears in first-class condition.

The conductor must in all cases notify the enginemen and trainmen that a car containing explosives is on the train and where it is in the train before leaving the initial station.

Conductors must frequently inspect such cars to see that the carding is intact. When any of these cards become detached or lost in transit, the conductor will give notice thereof, on arrival at the next division terminal Yard, to the yardmaster or other person in charge, who must attend at once to recarding the cars as required.¹

(c) At points where trains stop, trainmen must examine cars carded as containing explosives and adjacent cars to see if they are in good condition and free from hot-boxes or other defects liable to cause damage. If cars are set off short of destination from any cause, the conductor must notify the nearest agent, who must see that every precaution is taken to prevent accident. The conductor must also notify the Superintendent from the first telegraph office.

(d) A car carded as containing explosives must be placed as near center of train as possible, and, when practicable, not closer than fifteen (15) cars from the engine or ten (10) cars from the caboose, unless length of train will not permit,² and must have its air-brake and hand-brakes in service and be placed between cars with air-brakes in service. It must be placed between two box-cars in good condition, not loaded with oil or other inflammable mate-

¹ It is recommended by the Committee that all way-bills for shipments of explosives be stamped "Explosives," or that a special card be attached to the way-bill showing the nature of the shipment.

² This applies to cars in the ordinary current of traffic on main lines. For movements on branch lines, equivalent to switching movements, such special regulations should be made by each road as will suit the conditions of the service.

rial, lumber, iron, pipe, or other articles liable to break through end of car from rough handling. Cars containing explosives must not be placed in a train within five cars of each other, and not more than three such cars placed in any one train.

(e) **Handling in Yards.**—In handling cars carded as containing explosives in yards or placing on sidings, they must, when practicable, be coupled to the engine protected by a car between, and the car not cut off while in motion. It must be known that the hand-brakes are in good condition. Other cars must not be allowed to strike a car carded as containing explosives. They should be so placed in yards or on sidings that they will be subject to as little handling as possible and removed from all danger of fire.

29. AGENTS AT DESTINATION AND TRANSFER STATIONS MUST SEE THAT THE CARDS PRESCRIBED IN RULE 20 ARE REMOVED FROM CAR AS SOON AS THE EXPLOSIVES ARE UNLOADED.

30. Agents must furnish all the shippers of explosives within their territory with copies of these regulations.

31. **In Case of a Wreck.**—In case of a wreck involving a car containing explosives, the first and most important precaution is to prevent fire. Although most of the group "high explosives" will burn in small amounts quietly, and without causing a disastrous explosion, yet it must be remembered that it is the characteristic of most explosives to burn, and consequently everything possible must be done to keep fire away. Before beginning to clear a wreck in which a car containing explosives is involved, all unbroken packages should, if possible, be removed to a place of safety, and as much of the broken packages as possible gathered up and likewise removed. Furthermore, it should be borne in mind that "high explosives" are readily fired by a blow, and all explosives, except when they are wet, by the spark produced when two pieces of metal or a piece of metal and a stone come violently together. In clearing a wreck, therefore, care must be taken not to strike fire with tools, and in using the crane or locomotive to tear the wreckage in pieces,

the possibility of producing sparks must be considered. With such explosives as "common black powder," "smokeless powder," and "fulminates," thorough wetting with water practically removes all danger of explosion by fire, spark, or blow; but with the "high explosives" wetting does not make them safe from blows. With all explosives, mixing with wet earth renders them safer from either fire, spark, or blow. In case any "fulminate" has been scattered by a wreck, the ground involved must be saturated with oil after the wreck has been cleared. If this is not done, when the ground and fulminate get dry, small explosions will constantly occur whenever the mixed material is trodden on or struck.

.....R..

Manufacturer's Certificate of Contents and of the Method of Packing and Marking Packages of Explosives.

Delivered at.....Station, for transportation
to.....on.....190

I CERTIFY that the explosives in each of the packages of ¹.....
.....in this shipment, which are offered subject to the conditions of the Bill of Lading of which this certificate forms a part, are properly made, packed, and marked as required by the Regulations for the Transportation of Explosives (General Notice No. —), copy of which I have carefully read, and that none of the packages contains any other explosive than is designated by the marking.

I ALSO CERTIFY (if the shipment consists of Common Black Powder or Smokeless Powder in iron or steel kegs) that the iron or steel kegs used will stand the required tests and that the filling-hole of every package is securely closed; and (if the shipment consists of Small-Arms Ammunition) that no single cartridge contains a projectile weighing as much as one pound.

.....

Manufacturer.

This certificate, after it has been signed, must be delivered to the station agent, who will keep it on file.

¹ In this space the name of the explosive should be given, as follows: Common Black Powder, High Explosives, Smokeless Powder, Fulminate, Small-Arms Ammunition, Great-Gun Ammunition, or Fireworks.

.....R..

United States Government Certificate of Explosives Offered for Transportation.

For transportation to.
.....190 .

I CERTIFY that the explosives in this shipment offered subject to the conditions of the Bill of Lading, of which this certificate is a part, are manufactured and packed in accordance with United States Government Regulations.

.....
.....

This certificate, after it has been signed, must be delivered to the station agent, who will keep it on file.

.....R..

Shipper's Certificate of Explosives Offered for Transportation.

Delivered at.....Station, for transportation
to.....on.....190

I CERTIFY that none of the packages of ¹.....
in this shipment, which is offered subject to the conditions of the Bill of Lading of which this certificate forms a part, has been opened or changed by me since its manufacture, and that these explosives are in the original packages as manufactured.

.....
Shipper.

This certificate, after it has been signed, must be delivered to the station agent, who will keep it on file.

See Interpretation No. 4.

.....R..

Certificate of Inspection of Car Containing Explosives.

.....STATION.....190

We hereby certify that we have this day personally examined.....
.....car No....., and that the roof and sides have no loose

¹ In this space the name of the explosive should be given, as follows: Common Black Powder, High Explosives, Smokeless Powder, Fulminate, Small-Arms Ammunition, Great-Gun Ammunition, or Fireworks.

boards, holes, or cracks; that the doors close so tightly, or have been stripped so that sparks cannot get in at the joints; that the king-bolts or draft-bolts are properly protected, and that there are no irons or nails, projecting from the floor or sides of the car which might injure packages of explosives; also, that the floor has this day been cleanly swept before the car was loaded, and that we have examined all the axle-boxes, and that they are properly packed and oiled, and that the explosives in this car have been loaded according to sections 24, 25, and 26 of the Regulations for the Transportation of Explosives (General Notice No. —).

.....
 _____ *Agent or Inspector.*

.....
Shipper.

See Interpretation No. 8.

INTERPRETATIONS.

The Committee on Transportation of Explosives of The American Railway Association has rendered the following interpretations of the Regulations:

(1) **General Notice, second paragraph.**—It having been brought to the attention of the Committee that shipments for the United States Government are sometimes made in its behalf by Civilian Employés, the Committee has decided that a certificate from such an employé, duly authorized to sign for such shipments, should be accepted as equivalent to a certificate signed by a duly authorized non-commissioned or warrant officer.

(2) **Regulation 3 under Group 2. Common Black Powder—Marking.**—The mark “Common Black Powder” should be placed on all kegs holding twenty (20) pounds or over. For smaller kegs, if boxed, the marking on the box is sufficient.

(3) **Regulation 5 under Group 3. High Explosives—Packing.**—The regulation as to one-inch thickness of the ends of boxes refers to boxes where the sides are nailed to the ends. The Committee considers boxes to be of equivalent strength with ends one-half inch thickness, if made with lock corners.

(4) **Shipper's Certificate of Explosives Offered for Transportation.**—In the case of small-arms ammunition, “the original package as manufactured” is the smaller pasteboard box in

which the cartridges are placed. In the case of kegs of black powder holding less than twenty (20) pounds, or of smokeless powder holding less than ten (10) pounds, the original packages are the kegs. In both cases they must be inclosed in wooden boxes for shipment. In the case of all other explosives, the original packages are the packages as packed by and received from the manufacturer.

(5) **Regulation 5 under Group 3. High Explosives—Packing.**—"Boxes should be painted on the inside or lined with paraffin paper, or otherwise treated so that the liquid constituent of the explosive will not be absorbed by the wood." The word "should" is simply permissive as to the method to be employed. Wood which has absorbed the liquid constituent of a high explosive is dangerous. Some method, either by painting or otherwise, which will prevent this absorption, must be employed in order to comply with Regulation 5.

(6) **Regulation 17 (g). Selection and Preparation of Cars.**—It is only necessary that the certificate should be signed by the shipper in case he loads the shipment. In other cases the agent's certificate is sufficient.

(7) **Regulation 23. Handling of Explosives.**—The question of whether the purpose of the regulation can be better conserved by handling packages on trucks especially adapted to that purpose, rather than entirely by hand, as provided for in Regulation 23, is one that must be determined by the officers of each road in accordance with local conditions.

(8) **Certificate of Inspection of Car Containing Explosives.**—The Committee has decided that the original should be filed with the agent through whom shipment is made.

(9) **Regulation 3 under Group 2. Common Black Powder.**—The fact having been called to the attention of the Committee that in United States Government shipments it is necessary for the purposes of identification to distinguish between "Common Black Powder" and Brown "Prismatic Powder," which are classed under one heading in Group 2 of the Regulations for the Transportation of Explosives, the Committee has decided that

when packages containing Brown Prismatic Powder are packed as provided in Regulation 3 and are plainly marked "Brown Powder," this marking should be accepted as satisfactory.

(10) **Regulation 25. Loading in Car.**—The question has been asked whether under Regulation 25 the loading of small-arms ammunition and great-gun ammunition in the same car with each other is prohibited. The answer of the Committee is, No.

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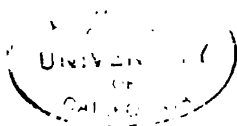
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